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Frontispiece.

CUMULUS CLOUD. Photographed by Mr A M'Adie, U.S. Weather Bureau, San Francisco.

THE STORY OF THE ATMOSPHERE

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WITH FORTY-FOUR ILLUSTRATIONS

LONDON: GEORGE NEWNES, LTD.
SOUTHAMPTON STREET, STRAND

PREFACE.

I HAVE desired in the present little work to put forward the main features of our knowledge of the conditions which prevail in our atmosphere as they are interpreted through the science of to-day. The Atmosphere, unlike its solid partner, contains no gold or coal mines with which to stimulate scientific research. Its study has consequently been somewhat neglected until of late years, and is even now only just emerging from the stage of myth and speculation into that of fact and certainty.

This desirable result has been chiefly attained by the disuse of vague hypothesis and the application of the known laws of physics.

I have therefore written, not for the minority, who vaguely wonder at the relation of extraordinary facts and pass on, but for what I believe to be that much more numerous section who are not content with a mere collection of facts, but want to know the reason why.

I have levied largely upon the original works of the more modern school of meteorologists which is so ably represented in America, India, and Germany—and am under especial obligations to those of Prof. Davis of Harvard, Prof.

Loomis of Yale, Mr Ferrel of Washington, Prof. Sprung, and Prof. Waldo.

I have purposely omitted the subject of weather and descriptions of instruments, and only briefly touched upon climate, and have rather endeavoured to shew, especially in the chapter on Flight, that the Atmosphere possesses growing uses and interests quite apart from, and in addition to, its consideration as a vehicle of weather.

DOUGLAS ARCHIBALD.

1897.

CONTENTS.

LIST OF ILLUSTRATIONS.

THE STORY OF THE EARTH'S ATMOSPHERE.

CHAPTER I.

THE ORIGIN AND HEIGHT OF THE ATMOSPHERE.

THE atmosphere of air in which we live and breathe is really a part of the solid globe on which we stand.

Until we think of it, we might be inclined to imagine we were surrounded by mere space, but when we place our heads under water we find we cannot live more than a few seconds without inhaling this same air, and we have only to look at our ships sailing, our windmills rotating, and our slates blowing off our roofs in a storm, to be certain that it is just as *material* as the solid earth to which it clings.

Its past history, unlike that of its more solid partner, is not written in the unmistakable language of successive rock strata, or fossil remains, and we can only infer something of its ancient changes from analogy with what is now occurring in the sun, and a knowledge of the physical history of the universe.

If we are to believe the "nebular theory,"

propounded years ago by the great French astronomer, La Place, and which, far from being upset, has rather been confirmed by recent discovery, all existing suns and planets have been simply condensed from clouds or nebulæ of matter originally scattered through space.

By the mutual attraction of their matter (which force we now term gravitation), these separate aggregations became highly heated globular masses, every element of which was at first in a state of fiery gaseous incandescence. As they gradually cooled and threw off planetary excrescences, these masses became condensed at first into liquid spheres or suns, surrounded by atmospheres of the lighter and less condensible gases, still hot enough to be luminous. Of such a type is our own sun.

A further stage of cooling took place, particularly amongst the planetary offspring, during which the liquid cooled enough on its external surface to form a thin solid crust, beneath which it still remained more or less liquid, and above which enough gases still remained uncondensed to form a thin atmosphere, through which light and heat could penetrate, and yet substantial enough to support animal life. This is the present condition of our own planet.

We must not, however, suppose that this state of things holds on every other planet. The rate at which such changes progress is different for each planet.

The planet Jupiter is still so hot that it is believed to be partly self-luminous, and its atmosphere probably contains clouds and vapours

of substances which on our cooler earth have long since condensed into liquids or solids. Through the telescope it is seen to be covered with dense clouds, and most of its water probably still exists in the form of vapour (or water gas), and not in liquid seas as on our own globe. The planet

Photo by *G. W. Wilson, Aberdeen.*

FIG. 1.—STRATO-CUMULUS (LOW).

Mars, on the other hand, has so little water left in its atmosphere or on its surface that, while enough remains to supply its polar caps with snow during the winter, its parched equatorial deserts are believed by Mr Lowell, of the Arizona Observatory, and others who have made it a special study, to be irrigated thence by the

system of so-called canals which intersect its surface.

Finally, our moon presents a picture of the condition eventually reached by a small globe—viz., all solid, no liquid, and no gas left. Therefore, according to our ideas, no life would be possible on the moon. The liquid, which would be chiefly water, has been absorbed into the solid substance of the moon, while the last relics of the gaseous atmosphere, which it once must undoubtedly have possessed, have been either absorbed into its mass or else diffused into space beyond the power of recall by gravitation.

The condition of each globe at present depends chiefly on the rate at which these changes from all gas, to gas and liquid, and thence to gas, liquid, and solid, occur—*i.e.*, on their rate of cooling. The larger the globe the longer it takes to cool.

The final condition, however—viz., whether a globe ultimately ceases to possess a liquid or gaseous covering, and becomes like our moon, or still retains an atmosphere and oceans like our earth, depends on the attraction (gravity, as we term it) by which it holds its gaseous portions to it. This, again, directly depends on the amount of matter it contains, and therefore again upon its size. Thus, our earth will probably never lose its atmosphere altogether, though considerable quantities of the lighter gases, such as hydrogen, have no doubt already escaped into space.

The fact, therefore, that we possess at the present time a gaseous atmosphere of exactly that particular degree of tenuity that suits our

breathing apparatus, remarkable though it may seem, is a direct consequence of the particular size of the globe on which we stand.

Back through the corridors of time, before the earth had sufficiently cooled to acquire a solid crust, we were a little sun, with an atmosphere of hot, turbid, metallic vapours which poured down metallic rain, only to be boiled off again on approaching the heated surface. After a time, however, such metallic rain would cease to rise again, and remain a part of the solidifying earth; and by the time that geologic history commenced and the surface was cool enough to admit of animal and vegetable growth, the atmosphere must have been practically as clear as it is to-day.

In proof of this we find that those remarkable trilobites or sea-lice of the Silurian period, which is nearly the oldest of which we have any knowledge, were endowed with organs of vision, which shew that as much light penetrated the seas then as now. The atmosphere, therefore, must have been equally transparent. Doubtless, more vapour and carbonic acid were present. Indeed, some of the latter has since been locked up in a solid form in the coal measures and limestone rocks of subsequent epochs.

Continuing our globe history, there came a time when the atmosphere, after being heated mostly from the still warm earth, began to find its solid partner no longer the warm friend of its youth, and found itself compelled to depend on the solar beams, albeit after they had travelled through ninety-three million miles of space, to

protect it from the terrible cold of space. By receiving and entrapping such rays, it is even now enabled to keep some 500° Fahr. warmer than outside space, while the heat which at present reaches it from the earth is estimated as being barely enough to raise it $\frac{7}{100}$ths of a degree in temperature.

The atmosphere of our planet, therefore, is our own individual property, and in no sense part of a universal atmosphere spread all over space. In fact, if such a general atmosphere existed at all, it has been calculated by Dr Thiesen of Berlin that our sun would, by virtue of its enormous size—a million times that of our earth—and gravity, which is twenty-seven times greater, attach to itself a gaseous covering or atmosphere, which would be as dense as our own, far beyond the orbit of Venus. This, however, is known to be contrary to fact.

The sun's atmosphere is not more than about 500,000 miles deep, while that of the earth is certainly not more than 100 miles.

The height of our atmosphere has never been measured as we measure distances on the earth's surface, for the very simple reason that we can never hope to reach the top. Indeed, we should find it very difficult to know where the top was, even if we were able to approach it, since the air would shade off so gradually into where it suddenly changed into the vacuum of space that we should with difficulty discover the place where we could say "thus far and no farther."

We can, however, arrive at some knowledge of the probable height to which the air exists in

such quantity as to possess weight and resistance by calculation of the rate at which the pressure of the atmosphere diminishes as we ascend, and also by observation of the duration of twilight and the heights at which meteorites (or, as they

Photo by *G. W. Wilson, Aberdeen.*

Fig. 2.—Strato-Cumulus (high).

are still popularly termed, falling stars) are visible.

Living as we do at the base of our ocean of air, like the flat-fish live at the bottom of the ocean of water, we are absurdly ignorant of the

condition of the atmosphere a few miles overhead.

The highest ascent made by man up mountains is believed to be that of Zurbriggen on Aconcaqua, when he reached about 24,000 feet, or a little over 4 miles, while the highest in a balloon was that made by Dr Berson of Berlin, who in 1894 ascended to a height of 30,000 feet.

Some years ago, in 1862, Glaisher and Coxwell made a memorable ascent over Wolverhampton, when they became unconscious at 29,000 feet, after which they were supposed to have ascended for a short time, to nearly 36,000 feet, but in Dr Berson's case, by inhaling oxygen he was able to observe his instruments and carefully note the conditions around him.

His thermometer went down to 54 degrees below zero Fahr., while the mercury in his barometer sank from 30 to 9 inches. Six miles is probably the limit to which man will ever care to ascend into the atmosphere, since above this height he can only survive by the aid of artificial assistance. For permanent habitation it is found to be prejudicial to live at greater heights than 15,000 feet, so that it is only within a thin slice of our atmospheric blanket that human life is lived. Actually, the marvellous complexity of human thought and action, and the development of modern civilisation on this earth, has taken place, and will probably always remain confined within the vertical distance of a London shilling cab fare above the surface.

Apart from direct measurement, the pressure of the atmosphere gives us some clue to its

height as well as to its weight. From the pressure observations alone, it ought to disappear somewhere about 38 miles, since at that height the mercury column of the barometer, which measures the weight of air above, would tend to disappear. Observations of meteorites, however, whose appearance depends upon their heating to incandescence by friction against a resisting medium, shew that some air exists at 100 miles, though at such great altitudes it is probably in a condition of extreme rarity. Observations of the duration of twilight, which is due to reflection from particles of dust and air, gave about 50 miles as the limit. Practically, therefore, we may take 50 miles to be about the limit up to which the atmosphere exists in a coherent form as we know it near the earth's surface.

CHAPTER II.

THE NATURE AND COMPOSITION OF THE ATMOSPHERE.

To one of those superior beings who, we believe, inhabit the celestial regions, it must be infinitely pathetic to see the poor little human mites on this planet struggling for centuries through the mist of error and superstition, until they finally discovered one day the composition of the atmosphere in which they lived. By the Greeks the air was considered to be one of the four elements,

and it was not until the middle of the last century that Priestley discovered that air was a mixture of oxygen and nitrogen, and that its neutral character was due to the blending of a most active element, oxygen, with a most inactive element, nitrogen.

A slight difference in the proportion of either

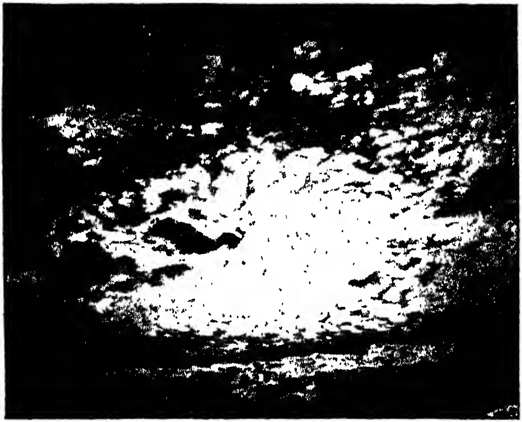


FIG. 3.—CIRRO-CUMULUS.

element would be fatal to life as we know it. With more oxygen in the air our lives, short enough as they are, would be still more brief, and though we might be more witty and brilliant, we should live in a state of such mental and physical intoxication that we should never be able to sit down quietly to do any solid work.

In fact, the human race would be converted into a number of thoughtless, reckless, frivolous beings, who would probably end by destroying each other in a frenzy of over-excitement. On the other hand, too much nitrogen would reduce us to such a degree of dulness and inertia that our supposed national characteristics would be intensified and we should become like a row of statues or mummies, without action or passion, lifeless—in fact, matter without motion. The existing proportion therefore is decidedly adapted to our present requirements. The average proportion in which the two principal components of the atmosphere are found to occur is 21 of oxygen to 79 of nitrogen by volume, and 23 of oxygen to 77 of nitrogen by weight.

The proportion in which the remaining constituents enter is so small that it may be practically neglected when we consider the physical properties of the atmosphere, though it cannot be neglected when we regard its vital and chemical functions. The other constituents are carbonic acid, which occupies $\frac{3}{10000}$ths by volume, traces of ammonia, ozone, and the recently discovered argon, krypton, neon, helium, metargon, etc.

Oxygen, which forms one-fifth of the atmosphere, represents the active vitalising principle, a large proportion of which, by its former chemical union with certain terrestrial elements, such as silicon and aluminium, has solidified into large rock masses, by union with hydrogen, has produced the liquid ocean, and the gaseous vapour of the atmosphere, and which, by its chemical union with carbon through the tissues of plants

and animals, developes the energy which is manifested in their life and movements.

Owing to the fact that the density of oxygen is very nearly the same as that of nitrogen, and to the constant mixture which takes place, the proportions in which they are found at high elevations differ but little from those at sea-level.

Thus in a balloon ascent at Kew, the percentage of oxygen present at a height of 18,630 feet was found to be 20·88, while it was 20·92 at the surface, where it varies chiefly according to the lack of ventilation and the number of people who inhabit confined spaces. In the pit of a theatre the percentage is 20·7, in a law court 20·6, and in the gallery of a theatre about 20·5.

So far as its chemical properties are concerned, therefore, the atmosphere at great heights is just as suitable for man as it is at sea-level. The only practical drawbacks arise from its greater rarity and cold, as we ascend from the surface.

The Nitrogen, which forms three-fifths of the atmosphere, represents the inert, negative element which, though not actively hostile to life, by diluting the oxygen, lessens the activity and rapidity of the energy developed by the latter's combustion, and thus tends to prolong life, which would be used up too rapidly in pure oxygen. It would not be easy, in fact, to find any other diluent of oxygen which could take the place of nitrogen without producing poisonous effects like those of carbonic acid.

Regarded from a physical point of view,

nitrogen, being slightly less dense than oxygen in the proportion of 97 to 110, renders the air a better vehicle for sound, support, and power than it would be otherwise.

Nitrogen is also absorbed from the atmosphere by plants, through the agency of those marvellous little bacilli parasites, the Nitragin, which have recently been shewn by Prof. Dobbé to nourish certain plants by abstracting the nitrogen from the air and passing it into the substance of the plants. Each plant, moreover, appears to be fed by its own special bacillus, but starved by that of any other plant.

The carbonic acid only forms a very small percentage of the air, but nevertheless plays an important part in the operations of nature.

Animals consume oxygen and exhale carbonic acid as a product of their respiration. Plants, on the other hand, under the action of light on their green cells decompose the carbonic acid, absorb the carbon, and liberate the oxygen. By these means the balance between supply and consumption is about maintained.

In former periods of the earth's history the amount of carbonic acid in the atmosphere was probably much greater than at present. Especially during the carboniferous epoch of geology, when owing to special climatic conditions enormous quantities of trees and ferns grew which abstracted the carbon from the then existing atmosphere, and by burying it for centuries in the solid form of coal all over the world materially reduced the subsequent proportion of carbonic acid from what had previously existed. Though ·03

per cent., the amount existing at present seems a small quantity, it is yet as we know, enough to supply all the vegetable world with its solid carbon.

Huxley once calculated the amount of this gas which is contained in a section of the atmosphere resting on a square mile to be as much as 13,800 tons, while the amount of solid carbon which could be extracted from such a quantity of the gas would be about 3700 tons, enough to supply a small forest of trees weighing 7400 tons.

Ozone, of which traces exist in the atmosphere, is a peculiar form of oxygen, a molecule of which is composed of two atoms linked together, and a third which, on the principle of two is company and three is none, is inclined to walk off whenever it meets with a suitable companion. Fortunately for man the tastes of this third atom are distinctly low, since it has a partiality for sewers and places where matter is decomposing and which by its active oxidising power it renders neutral and harmless. Since towns usually contain more of such deleterious conditions than the country, more ozone is found on their windward than on their leeward sides.

Ozone prevails most in the spring months and least in the autumn, and while it probably acts beneficially as a rule, by its active oxidation of poisonous gases, its excess is associated with the prevalence of certain forms of catarrhal disease.

Traces of ammonia occur which help to supply nitrogen to the soil and plants when washed down by rain. Every year about 30 lbs. of ammonia are carried down to each acre of ground.

The above constituents are blended together like different brands of spirit, but are free to enter into combination with other substances. This freedom of contract is implied in the term mechanical union, which is employed to distinguish the mixture of oxygen and nitrogen forming atmospheric air from that of the chemical union between oxygen and hydrogen in the compound water.

The vapour of water which as an invisible gas is generally more or less associated with dry air may be looked upon as a separate atmosphere of gaseous water. The fact, however, that it is impossible to distinguish it from dry air by sight or smell, and that until it condenses out of the latter as rain or cloud it virtually forms one of its components, makes it desirable for us to regard it in this light, if we are careful to remember that its quantity (generally about 1 per cent. by weight) is ever varying, and that the volume of dry air it displaces and occupies itself, depends on the temperature as well as the mass of it present. When it occurs as an invisible gas it is $\frac{5}{8}$ths as dense as dry air at the same temperature and pressure. The peculiarity of the position of aqueous vapour is, that if it existed alone on the earth, there would be only one temperature at which it would change from a gas into a liquid, and therefore only one level at which cloud would form and whence rain would descend altering with the time of day and season.

Since, however, it exists in combination with air, it spreads upwards until it arrives at the particular temperature at which the air fails to

support it in solution, when a layer of cloud forms and perhaps rain falls. After this an interval occurs in which the vapour is at first in defect, but as we ascend, its relative amount to that which is capable of being sustained increases until another level and temperature is reached at which condensation takes place, and a second stratum of cloud is formed and so on. Ultimately a point is reached at which the vapour-sphere nearly vanishes, but this must be very high, for although it is found that at a height of 23,000 feet in the Himalaya the amount of vapour in the air is only one-tenth of that which exists at sea-level, while at 46,000 feet it would only be one hundredth, cirrus clouds have occasionally been seen above the latter level.

Dust is another constituent which plays an important rôle. Mr John Aitken of Glasgow has made this question the subject of special investigation, and has found that the atmosphere, especially in its lower parts over land, contains thousands of particles of the finest dust. Over the sea and in its loftier regions these particles are much less numerous. He has also found that the presence of this dust is necessary to the formation of rain.

A recent series of observations by Mr E. D. Fridlander, taken with Aitken's pocket dust counter in various parts of the world, embracing the Atlantic and Pacific Oceans, New Zealand, California, the Indian Ocean, and Switzerland, shewed that these tiny dust particles are found in the lower atmospheric strata right out in the middle of the Pacific Ocean as well as on land,

and especially in towns. They are, however, less numerous at sea, especially in the Pacific and Indian Oceans. Thus comparing all three oceans we have at sea-level.

	Number of dust particles per cubic centimetre.*
Atlantic Ocean . . .	2053
Pacific ,, ...	613
Indian ,, ...	512

As low a value as 210 was found in the Indian Ocean after rain. On the other hand, over land areas the number frequently rises to 3000 or 4000 per cc. In large cities such as Edinburgh, Paris, and London, where the products of animal and fuel combustion enter the atmosphere in large quantities, the lower atmosphere is so polluted that in some cases as much as 150,000 dust particles in a single cubic centimetre have been counted.

As we rise above the surface the number of dust particles is found to diminish pretty regularly with the ascent. From observations on the Bieshorn, Fridlander found the number gradually diminish in the following ratio.

Height above sea-level.	Number of particles per cc.
6,700 feet	950
8,200 ,, ...	480
8,400 ,, ...	513
10,665 ,, ...	406
11,000 ,, ...	257
13,200 ,, ...	219
13,(00 ,, ...	157

* About 15 cubic centimetres are equal to 1 cubic inch.

The general rule for the diminution in the number of dust particles may be simply expressed thus: For every rise of 3000 feet the amount is $\frac{4}{5}$ths of what it was at the lower level. The bearing of this fact on the question of the beneficial influence of high mountain resorts on pulmonary and other diseases is obvious.

These same minute dust particles, by their scattering action on the small waves of light at the violet end of the spectrum, have been shewn by Lord Rayleigh to be the cause of blue sky, while its gradual deepening into black as we ascend is readily seen to be the result of their gradual diminution in number.

CHAPTER III.

THE PRESSURE AND WEIGHT OF THE ATMOSPHERE.

ONE of the first facts which is brought to our notice in these days when those physical laws, which the ancient philosophers discovered towards the end of their lives, are taught us from childhood, is that the air has weight and exerts pressure. The story of the discovery of the barometer or weight measurer is a romantic chapter in the history of science.

About 1643, some Florentine gardeners found that they were unable to pump up water higher than thirty-three feet. Up to that time it was an accepted dogma that "Nature abhorred a

vacuum," and this apparent lapse on the part of Nature was looked upon as inexplicable. When Galileo was informed of it, soured as he was with a world which had rejected some of his greatest discoveries, he cynically remarked that Nature evidently abhorred a vacuum *up to* thirty-three feet. His pupil, Torricelli, however, was not content with this perfunctory explanation, and applying his genius to the question, conjectured that the column of thirty-three feet of water exactly balanced a similar column of air stretching to the limits of the atmosphere. Remembering that mercury was about thirteen times as heavy as water, he inferred that if this were true, a mercury pump would only raise mercury to a height of about 30 inches. He thereupon filled a long glass tube with mercury, and having stopped up one end, placed his thumb over the open end and inverted it over a basin of the liquid metal. The result proved his anticipations to have been well founded, since the mercury fell in the tube until it exactly reached this height of 30 inches, leaving what is known as the Torricellian vacuum in the upper part of the tube.

This is substantially the mercurial barometer by which to-day we measure what we term atmospheric pressure.

The reason the term *pressure* is employed and not *weight* is because air, in common with all fluids, not merely presses downwards, but equally in all other directions.

This is readily shewn by the familiar experiment of placing a bit of paper over the mouth of a bottle full of water, and inverting it, when the

water will be retained by the upward pressure of the air on the surface of the paper.

When we want to measure the weight of air, we must remember that, since air is elastic, it is more compressed, and therefore weighs heavier near the surface than up above.

At sea-level, where the barometer frequently registers a height of 30 inches, we shall find that at 32° Fahr. the column of mercury 30 inches high resting on one square inch weighs 14·7 lbs. It is easy from this, knowing that mercury is 13·6 times as dense as water, and air only $\frac{129}{100000}$ths as dense, to measure the weight of a cubic foot of pure dry air, which under these conditions will be about 565 grains (troy). On the top of a mountain 18,000 feet high it would only weigh half as much. The weight of a cubic foot of water vapour under the same conditions would be only 352 grains. From this it will be understood that, when vapour is mixed with dry air, the resulting compound is *lighter* — that is, damp air is lighter than dry air.

The weight of the atmosphere on the earth cannot be ignored.

A flood of water 33 feet high over the globe would represent the same weight, and would evidently exercise a very considerable pressure on the surface. Westminster Hall alone contains 75 tons of air, while the entire weight of air resting on the earth has been estimated by Sir John Herschel to amount to $11\frac{2}{3}$ trillions of pounds. Sudden alterations of this pressure, which are indicated by the rise and fall of the barometer, undoubtedly affect

some persons of a sensitive temperament, while the steady fall of pressure which occurs when we ascend a mountain or rise in a balloon occasions what is termed *mal de montagne* in both men and animals.

On the other hand, the excessive pressure experienced in diving-bells or in the Waterloo tunnel, where the men are now working under a pressure of two or more atmospheres, is found to bring on a species of paralysis.

To give a general idea of the decrease of pressure with the height when the barometer marks 30 inches at sea-level, we find the following relative scale for air of an average temperature and dampness.

Pressure.	Altitude.
30 inches	0
29 ,,	910
28 ,,	1,850
27 ,,	2,820
26 ,,	3,820
25 ,,	4,850
24 ,,	5,910
23 ,,	7,010
22 ,,	8,150
21 ,,	9,330
20 ,,	10,550
18 ,,	13,170
16 ,,	16,000

At 18,000 feet the pressure is about half that at sea-level.

It will be observed that at the lower elevations the height in feet corresponding to one inch in

the barometer is less than at the higher. The atmosphere is in fact more tightly packed near the earth, so that while 1 inch of mercury represents the weight of the first 900 feet of ascent, 1 inch at 16,000 feet represents the weight of about 1500 feet, and the proportion increases at greater heights.

Were the scale 1 inch of mercury to 910 feet of atmospheric air preserved all the way up, we should reach the limit of the atmosphere at about 26,220 feet, or 5 miles, which is the height of what is termed a homogeneous atmosphere.

Comparing the atmosphere with the ocean, we find that the volume of the former, assuming it to reach to a height of 100 miles, is as 65 to 1, while its mass bears to that of the latter the ratio of only 1 to 300.

The pressure at the average depth of the ocean —viz., two miles, is as much as 320 atmospheres.

The barometric pressure undergoes changes, some of which are irregular, and due to the passage of what are termed cyclones and anticyclones, in which the air is moving round moving centres, while others, such as those which complete their period in a year, are connected with seasonal transfers of air between sea and land and from hemisphere to hemisphere. Others, again, which run through their course in a day, are connected with the daily heating and cooling of the air by the sun, while certain short and nearly regular instantaneous changes over large areas, such as the five-day pressure oscillations recently noticed by Eliot in India, are still mysteries that require explanation. The seasonal

changes and the general distribution of pressure will be alluded to in future chapters, where they are considered with reference to dependent phenomena.

The *diurnal* variation of barometric pressure which is dependent on the daily rise and fall of sun-heat is largest, as we should expect, in the tropics, amounting to a range of as much as twelve hundredths of an inch at Calcutta, and diminishing thence as we travel polewards, until at Greenwich it is only about ·02 inch, or one-sixth of its tropical value. Nearer the poles it vanishes altogether. Between the tropics, the irregular changes of pressure introduced by the passage of storms are so small and infrequent that the diurnal variation is noticeable above all other changes, and is so regular that the late Mr Broun, of Trevandrum Observatory in India, used to declare he could tell the time of day by simply noting the height of the barometer. The rise and fall of the mercury column is a double one, reaching its greatest height at 10 A.M. and 10 P.M., and its least height at 4 A.M. and 4 P.M. The causes are not yet thoroughly worked out, since, although it undoubtedly depends on the action of the sun, the total effect is made up of a combination of direct and indirect motions of the air. In temperate regions the diurnal change of pressure is so small that it is almost lost sight of in those much larger pressure changes introduced by the passage of cyclones, which frequently amount to 1 or 2 inches' rise and fall of the mercury.

Barometric charts in which *isobars*, or lines of equal barometric pressure, are drawn over the

representation of different parts of the earth, will be referred to in chap. V. These charts are similar to those employed in weather bureaux in order to forecast the probable weather for the ensuing twenty-four hours.

One practical use of the barometer is to determine the altitude of a place above sea-level. The science of measuring heights by this means is termed hypsometry (from the Greek, *hypsos*, height, *metron*, measure). We have already seen that the pressure descends in a certain proportion as we ascend in the atmosphere, and formulæ have been determined by which the height may be calculated under certain conditions of temperature, humidity, etc. For rough and ready purposes, however, the following rule gives a very fair approximation :—

"*The difference of level in feet between two altitudes is equal to the difference of the barometric pressures observed at each in inches divided by their sum and multiplied by the number* 55,761, *when the average of the temperatures at the two places is* 60° *F.*"

When the average temperature of the two stations is above 60° the multiplier must be increased by 117 for every degree the average is above this temperature, and decreased in like manner for every degree it is below 60°. Thus, if the values at the lower station are 30·15 inches pressure and 65° temperature, and those at the upper station are 28·67 inches and 59°, a little household arithmetic will shew that the difference of their heights is 1409 feet.

CHAPTER IV.

THE TEMPERATURE OF THE ATMOSPHERE.

THE temperature of the atmosphere, whether we are aware of it or not, is a condition in which we are more directly interested than any other. The most common form of salutation in the street involves a dictum or a query as to "how cold it is to-day," "much warmer than yesterday," "I do hope we are going to have some really warm weather now," or "some skating," as the case may be. In all this the temperature of the air is concerned, since it is the medium in contact with us, and from which, chiefly by conduction, we derive our sensation of heat or cold. When we talk of temperature we must take care to know what we mean by the term. Heat, as we know, is a "mode of motion," as Tyndall used to call it, a vibration of the small molecules of a body, and directly this mode of motion is communicated to it, by what is termed radiation, it tends to return the compliment to other bodies in its neighbourhood, and set all their molecules in a similar state of oscillation. The process, however, is an exchange all round, and *the temperature of any body measures the rate at which it loses heat to or gains heat from surrounding bodies.* This rate depends upon its capacity for heat, and its power of absorbing and radiating heat rays, all of which vary in different bodies.

In the case of the atmosphere, the radiating power exceeds the absorbing power for rays

C

coming from the sun, but is considerably less for the heat radiated back again from the earth. So that, on the whole, the absorption power of the lower air for all kinds of rays is about $2\frac{3}{10}$ as great as its radiation power.

It is this property of the atmosphere which allows us to keep decently warm. Otherwise, were we bereft of this valuable covering or envelope we should shiver in a temperature of 138 degrees below zero Fahrenheit, which is probably the mean temperature of the moon's surface. The only advantage that could be claimed for such a temperature is, that it would be 332 degrees higher than what would probably ensue in the event of the sun becoming cold.

The temperature of the atmosphere is derived chiefly from the solar radiation which is arrested by the earth, and partly reflected, partly radiated back through the atmosphere towards space. Temperature is a *result* of radiation.

Consequently before we speak of the temperature it is necessary to see how radiation affects the atmosphere, since the conditions which regulate radiation, affect the temperature of the atmosphere in a somewhat similar manner.

When the sun's radiations have reached the earth's surface from which the lowest stratum of the atmosphere chiefly derives its temperature, their heating effect on a given area is modified by two circumstances, (1) their angle of incidence or the angle the direction of the sun makes with the horizon, and (2) the thickness of atmosphere they have traversed.

When a certain width of the sun's rays is con-

sidered it will be found to cover a smaller area in proportion as they fall more vertically or less inclined. Thus in the accompanying diagram

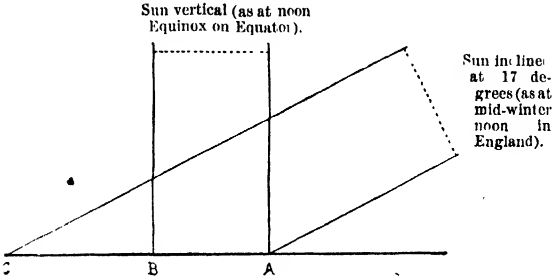


FIG. 4.

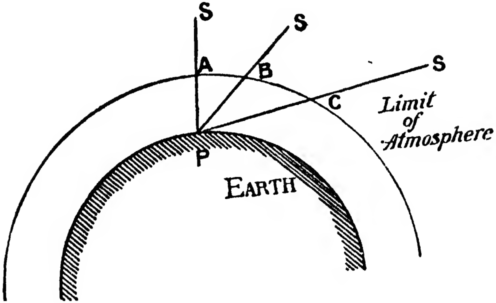
the same width of rays is concentrated upon A B in the one case, and spread over A C in the other, consequently the heat received by the earth is greatest when the sun is highest above the horizon, and shines most directly upon the ground. During a single day the heat received on the ground is greater at noon than at any other hour (about four times as great as at 10 A.M. or 2 P.M.). It is also greater in the summer when the sun is permanently at a higher angle all through the day after it has risen, than it is in the winter. These both operate together at any place on the earth. When we change our latitude we can, by travelling towards or from the equator at the rate of about 18 miles per day, obviate the seasonal change in the angle of the sun above the horizon and secure the same general amount of sun radiation. We should

not, however, be able to secure the same average temperature since the direct effects of the radiation on temperature are modified by what goes on over entire hemispheres. Moreover the effect of changing our latitude introduces another consideration which has a potent influence upon the amount of heat falling in the 24 hours—viz., the time during which the sun remains above the horizon. This time increases as we travel polewards in the hemisphere which is enjoying summer. There are thus two influences which work in opposite directions, one, the general angle of the sun above the horizon, which diminishes as we leave the equator, and the other, the length of the day, which increases under the same conditions. The conjoint effect must therefore generally reach its maximum value at some intermediate latitude.

As a matter of fact, this important problem has been worked out by several physicists, including Lambert, Poisson, and Meech. The last-named finds that on the average of the year, as we should expect, more heat falls on the equator than elsewhere. If we take the six months of the northern summer, more heat falls on latitude 25 degrees north (the latitude of northern India) than on the equator. If again we take the three months nearest midsummer, *i.e.* from May 7th to August 7th, the zone of greatest heat reception lies in 41° N., while from May 31st to July 16th, more heat falls on the North Pole than on any other part of the earth. The temperature of the Pole does not of course

at once respond to this heating, since the average temperature effect lags about one month behind the solar radiation, and near the Pole the heat is mainly employed in melting the Arctic ice floes, and in raising the temperature of the water. At the same time this beneficial arrangement obviously prevents the temperature there from becoming as low as it otherwise would.

In addition to this, the amount of heat which is transmitted through the atmosphere so as to reach the surface at all, varies with the angle of



the sun for a different cause—viz., the different thickness of the atmosphere traversed in each case.

This is plain from the adjoining figure in which as the sun's rays fall vertically or inclined, we have the thicknesses A.P., B.P., and C.P.

This last circumstance exaggerates the difference caused by the hourly and seasonal changes in the angle of the sun, especially as it approaches the horizon.

Direct observations of the sun-heat by means of an instrument termed an actinometer, which has been employed with great success by Prof. S. P. Langley at Washington, have shown that of the heat which falls vertically on the upper surface of the atmosphere, 25 per cent is absorbed (Langley says 40 per cent, but this seems doubtful from other considerations) before it penetrates to the earth. When the rays are inclined, instead of 75 per cent being transmitted, only 64 per cent arrives at an angle of 50 degrees, and only 16 per cent at an angle of 10 degrees. The light varies in the same way. At sunrise and sunset the sun has only $\frac{1}{1345}$th part of the brilliancy it possesses when vertical overhead.

When we come to consider the actual quantity of heat that is received from the sun, we shall see how utterly it transcends all our means for deriving warmth from (so-called) artificial sources. The intensity of solar heat may be measured by the temperature to which it would raise a certain quantity of water. If we suppose the rays which fall vertically on an area one square foot at the outside of the atmosphere, before any absorption has taken place to be applied to warming up 10 lbs. of water, they would raise it 1 degree on a Fahrenheit thermometer in 1 minute.

By the time these rays have reached the earth, as we have seen, about $\frac{1}{4}$th of the original radiation has been absorbed or scattered by the atmosphere, and therefore only about 7 lbs. of water could be raised 1 degree per minute. This however gives us some faint idea of the enormous quantity of heat which is continually falling on

either the earth or the clouds. If we take the heat which falls on a square mile of the earth's surface per minute, we shall find that it would be enough to raise 560 tons of water from the freezing to the boiling point.

In a year, assuming that the sun's heat continually penetrated to the ground, this heat would suffice to melt a layer of ice about 178 feet thick over the whole earth.

The general effect has been popularly put by one writer in the following graphic manner, in which the different amount of heat received when the sun is inclined at different angles is properly considered.

"Suppose the earth one vast stable covered with horses, and suppose that as the sun's angle varied according to season and latitude, the horses arranged themselves so that no horse's shadow fell upon or underneath his neighbour; then the solar heat falling upon the earth converted into horse power, would be always represented by all these horses working continuously at their utmost strength."

Some of this heat energy is, no doubt, converted into mechanical energy in the winds, rivers, and rainfall, but a vast proportion of it is wasted so far as man is concerned, and it is plain, as both Lord Kelvin and Edison have recently pointed out, that we have still an immense source of power comparatively untouched, which can be drawn upon when our coal supply shows symptoms of giving out.

One effect has not been alluded to—viz., the

change in the distance between the earth and the sun, which are nearer to one another in December than in July. Theoretically the effect would in any case be small. Practically it is counteracted by the large mass of water in the southern hemisphere, which responds more slowly to an increase of heat than the northern land, so that on latitude 20 degrees S., where it reaches its greatest effect, it only adds $\frac{1}{16}$th to what would occur if the distance were invariable.

Since the temperature of the atmosphere results from the accumulation of altered solar rays, in surrounding objects which radiate them to one another, instead of passing them back at once into space, the temperature epochs will always *follow* those of direct radiation. Thus the highest temperature of the day does not occur at noon, but an hour or two afterwards. Similarly the highest temperature of the year occurs on an average a month after midsummer day, and a like retardation occurs for the lowest temperatures. At the Pole, where one long day and night occurs in the year, the coldest month is delayed to February or March, in the northern hemisphere. When the sun's rays fall upon water, or where the locality is naturally moist, the heat is conducted through the top layer, and in any case takes longer to raise its temperature. Where, as always occurs, part of the water is evaporated, nearly 1000 times as much heat is needed to convert it into vapour as will raise its temperature 1 degree Fahr. Consequently, not only does the temperature of the air over oceans rise and fall less daily and seasonally than that

over the continents, but the highest temperature of the year in maritime regions lags about 42 days behind midsummer day, while in the centre of the large continents, the lag is reduced to 25 days.

This slowness to rise and fall in temperature on the part of large masses of water, accounts for the equable temperature of the atmosphere of islands and coasts, compared with interiors of continents, and exerts an important influence in determining the changes in the general wind and weather system over oceans and continents in summer and winter.

The measurement of atmospheric temperature dates back like that of the telescope, to Galileo, who in 1597 devised the first liquid thermometer.

This consisted of a glass bulb, containing air, terminating below in a long glass tube, which dipped into a vessel containing a coloured fluid. The variation of the volume of the enclosed air, caused the fluid to rise and fall in the tube to which an arbitrary scale was attached. Galileo further invented the alcohol thermometer in 1611, which was adopted generally by the Florentines of that time.

The determination of the zero and some fixed point above it, by which to graduate the scale, appears to have taken years to evolve. Newton suggested a scale in which the freezing point of water was 0 degrees, and the blood of a healthy man 12 degrees, and subsequently Fahrenheit, to whose scale with characteristic conservatism we still adhere in this country, in spite of the

universal use of that of Celsius on the continent and in physical investigation, in 1714 took blood heat and that of a freezing mixture of ice and salt as his fixed points. Since then the freezing and boiling points of water have been taken as the fixed points on the thermometric scale.

Unlike the early Florentine thermometers, the modern alcohol and mercury thermometers consist of a bulb and tube, partially filled with the liquid, above which is a tolerably complete vacuum, allowing the liquid to move with perfect freedom up and down the tube.

For measuring rapid variations in the temperature of the atmosphere, it is necessary to have the bulb small, since where the bulb is large, the effect of an exposure to heat is considerably delayed. Consequently, for determining the true shade temperature of the atmosphere at any moment where it is difficult to obtain proper shade conditions, a small sling thermometer is by far the most accurate. By tying any thermometer to a string, and whirling it round until the reading does not alter, a very fair notion of the true temperature of the air can be obtained.

For standard purposes where momentary changes are not so important, thermometers with large bulbs are preferred, since by this plan the variations due to the expansibility of the glass bear a small ratio to the volume of mercury.

We have now-a-days advanced so rapidly in our methods of investigation, that instead of being content with two or three readings a day,

we require to know the continuous changes in the temperature of the atmosphere in places where it is impossible to make eye observations.

For this purpose the self-recording thermograph is employed, and by the use of such an instrument the temperature of the atmosphere can be registered on the top of mountain peaks only occasionally accessible, and in the free atmosphere by the elevating power secured by kites and captive or free balloons.

When we examine the observed facts as they present themselves, we find in the first place a constant diminution of the temperature of the atmosphere as we ascend from the earth's surface. This decrease of temperature with ascent varies somewhat in different latitudes, and is not the same in the free atmosphere as on mountain sides.

From Glaisher's balloon ascents the rate begins quite near the surface at about 7 degrees in every 140 feet, and finally diminishes to 1 degree in every 400 feet at 10,000 feet, the entire diminution of temperature from sea-level up to 10,000 feet being 34 degrees, or 1 degree in 300 feet. If therefore we take the temperature of London to be about 50 degrees on the mean of the year, a temperature of freezing point or in other words the snow line would be reached at an elevation of about 4500 feet or a little above Ben Nevis in the free atmosphere (the mean temperature at the top of Ben Nevis is about 30½ degrees F.). We have no mountains above this level, consequently we have no perpetual snows in these islands.

In India the initial rate of decrease of tempera-

ture is very much more rapid, amounting to 1 degree in the first 33 feet, but it slackens down to about 1 degree in 330 feet at 15,000 feet. On the average it is about 1 degree in 270 feet in stations away from the Himalaya where the mountain range appears to reduce the rate.

If we take the region of the North West Himalaya we shall find that the mean temperature of London would be reached at a height of 9600 feet, and the range of temperature throughout the year would not differ very much from that of England.

Most of the Himalayan sanitaria lie between 6000 and 7000 feet where the temperature is about 60 degrees, and possess climates similar to those of the Riviera and the coast from Marseilles to Genoa.

When therefore we wish to vary our climate as far as temperature is concerned, we can do so without changing our latitude by remembering that the temperature cools on an average about 1 degree for every 300 feet we ascend, or warms at the same rate as we descend the same distance. Since the mean temperature at the north pole is about 0 degree F. and at the equator between 80 and 90 degrees F., we can similarly alter our temperature 1 degree F. by travelling north or south about 70 to 80 English miles. As an illustration of a combination of these facts we can imagine a series of planes rising upwards from different points of the earth towards the equator along which the temperature would range on either side of a certain average throughout the year. These would rise to their highest

level over the equator, and their height in any latitude would show us at what elevation we should experience some particular temperature all the year round.

The vertical scale above sea-level is of course immensely exaggerated.

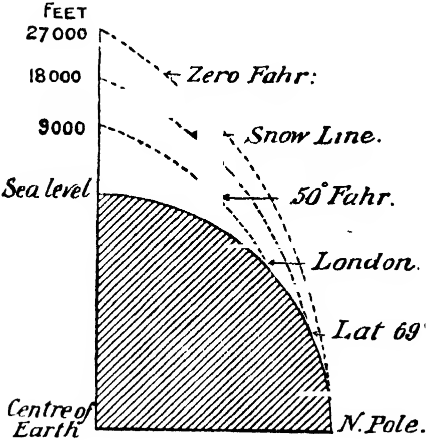


FIG. 6.

It will be seen that at an elevation of 27,000 feet over the equator, the temperature is about 0 degree F., and that the snowline or line of freezing point cuts the surface at sea-level about latitude 69° North.

In the Himalaya this line averages throughout the year about 15,400 feet above the sea, or about 17,850 feet in the summer months. Even this great altitude would still leave about 11,000 feet

of the higher summits mantled with perpetual snow during the summer.

There is perhaps no point about which so much perplexity is generally felt and expressed as the reason for this decrease of temperature as we ascend. It is often popularly expressed as being due to the greater rarity of the air above, but this simply leaves the matter as obscure as before. Like most other facts regarding the atmosphere, it results from the operation of a definite physical law.

It is well known that the rapidity of the cooling of a body depends on the perfection of its enclosure, whether solid or gaseous. At the earth's surface the enclosure is nearly perfect, but as we ascend, the upper side of the enclosure weakens owing to the thinning of the air, until at the top of the atmosphere the enclosure is only half what it was at the earth's surface. The heat radiated from the earth is moreover intercepted to a large extent at the higher levels by the intervening lower air. Consequently on both accounts the temperature of the air remains cooler in proportion to the altitude.

The distribution of the temperature of the atmosphere in a horizontal direction as ordinarily measured has reference merely to the temperature of the lowest stratum. Unlike the barometer which gives us the sum total of the pressures of the superincumbent layers, a thermometer near sea-level simply gives us the temperature of the particular stratum in which it lies. The magnitude of the daily and seasonal changes vary according as the locality is con-

tinental or maritime, and its soil is dry and rocky or damp and alluvial, and the average itself depends largely on these and other conditions besides mere latitude.

The general distribution however shews decidedly that latitude is one of the principal causes which affect the mean annual temperature. The map (fig. 7) shews the distribution of the heat in the lowest atmospheric stratum over the earth's surface on the average of the year, by lines of equal average temperature (isothermals). The principal points to notice are the widening out of the area between the isothermals of 80° over the land areas and the contraction that takes place over the seas, particularly the Atlantic. Also that wherever a marked dip of the line, particularly that of 70°, occurs toward the pole over the land, an equally marked dip of the line occurs in the opposite direction close alongside.

This is specially visible in California, Peru, and in S.W. Africa, and is plainly due to the known existence of cold marine currents flowing along these several coasts towards the Equator. So far as the British Islands are concerned it is equally plain that the northward flow of the gulf-stream of the Atlantic raises the isotherm of 50° F. which normally belongs to latitude 40° and passes through Nippon (Japan) ten degrees further north so as to make it pass through London. We thus get in these islands an atmosphere artificially heated up about 10 degrees (the isothermal of 40° F. properly belongs to our latitude) more than we are

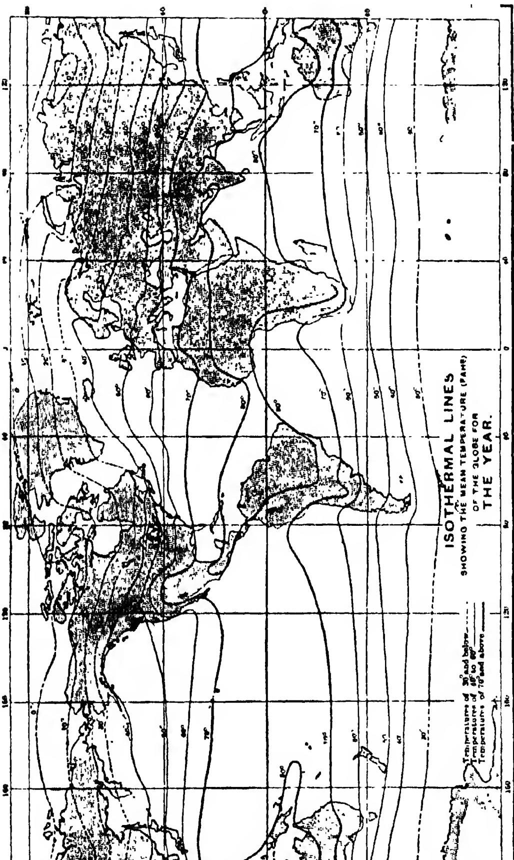

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR)
OF THE GLOBE FOR
THE YEAR.

FIG. 7

entitled to by our latitude. In like manner Peru no doubt enjoys several degrees less heat than it would otherwise have owing to the cool Antarctic stream (Humboldt's current) which flows up its coast and cools the lower atmosphere.

The area of greatest heat is where the largest land masses lie near the Equator, and of greatest cold where the largest land masses, such as N. Asia and N. America, lie nearest the Pole.

The reason for this is too important to be omitted.

If the same amount of sun heat falls upon an equal area of land and water it raises the temperature of the former four or five times as much as that of the latter.

Less heat energy is spent in agitating the molecules of dry earth than those of water. Consequently its effects are more patent. In the case of water the heat energy is not lost, no energy ever is in this Universe—but it is more latent and the expressed temperature is less. The atmosphere is more readily heated by the radiation from the hotter (as we say) earth than the cooler water. Consequently the lowest stratum over the land areas under the more direct sun near the Equator exhibits a generally higher temperature than that which lies over oceans in the same latitude. Since heating and cooling are reciprocal operations it is easy to see that the reverse applies to the temperature over polar seas and continents.

The migration of the sun north and south of the equator by reason of the inclination of the earth's axis to the plane in which the centres of

the sun and planets lie, causes a similar migration in the area of greatest heat north and south of the geographical equator. While the sun shifts from 23½° N. to 23½° S., however, the central line of greatest heat (or heat-equator) migrates to a less amount, particularly over the oceans. On the Pacific it moves only 15° to 20° in latitude. On the Atlantic still less. On the

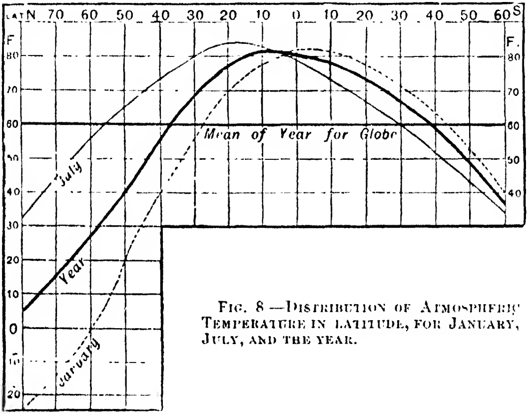


FIG. 8.—DISTRIBUTION OF ATMOSPHERIC TEMPERATURE IN LATITUDE, FOR JANUARY, JULY, AND THE YEAR.

land it shifts as much as 43° in Africa and 50° in America, while in India it runs up to the deserts of Persia in latitude 33° N. in the summer, and down to only 10° S. in the winter, because there are no southern lands to attract it further.

The general distribution in latitude and migration of the temperature may be best seen in the

accompanying diagram (fig. 8) plotted out from the means given by Ferrel.

The position of the thermal equator to the north of the line and the greater annual range of temperature in the northern hemisphere are plainly visible.

If we were to undertake a balloon voyage round the world at an average altitude of about 5000 feet we should find very few signs of this peculiar distribution which prevails near the surface.

The temperature over the equator would be about 64° F., an agreeable summer temperature in England, and though if we preserved the same elevation, the temperature would descend to about 34° over London, the seasonal and daily changes would be very much less conspicuous than near the surface.

By means of thermometers and thermographs the temperature of the atmosphere near the surface is read at certain hours or recorded continuously, and for various purposes particular attention is paid to its maximum, minimum, and average, either for a day of twenty-four hours, a month of 30 days, a year, or a series of years.

Where it is difficult to have continuous hourly readings taken, three hours are chosen, which, when combined in a simple manner, give a value which is found by experience to closely approximate to the average of the day.

Thus, the average of a single reading at 9 A.M. gives a very close approximation to the mean of

the twenty-four hours. Or we may add the readings at six, fourteen, and twenty-two hours and divide by three, or take the lowest and highest readings and divide by two. Where the self-recording thermograph is employed, the mean can be found by measuring the area traced out by the recording pencil and bisecting it.

The maximum and minimum in this case correspond to the highest and lowest points of the curve traced out, but usually they are measured by separate maximum and minimum thermometers.

Apart from the general distribution of its mean annual values shown in Buchan's isothermal chart, the temperature of the lowest air stratum and proportionally of those lying above it, is subject to regularly recurring daily and seasonal oscillations. These two series of changes are so important in their relation to our general comfort and welfare that it is of the highest interest for us to know whether they exhibit any signs of progressive change in obedience to law as we vary our position on the earth. As a general rule we find the greatest ranges of the temperature of the lowest atmospheric stratum between day and night occur in the driest parts of the earth, in the interior of continents, such as the Sahara, Arabia, Gobi desert, Rajputana, Colorado, etc., where it often amounts to 40° F., and the smallest ranges in small oceanic islands, such as Honolulu, Kerguelen, Madeira, Bermuda, where it is as small as 5° F.

In India, which presents the greatest contrasts

of dry interior and moist coast in the world, we have daily ranges of 30° to 40° in the Punjab, 20° to 30° in the Central Provinces, 16° at Calcutta, 8° at Bombay, and 6° at Galle in Ceylon. The daily range also decreases generally from the Equator to the poles when we take places at the same distance from the sea. Thus, while it is 11 degrees at Colombo, it sinks down to an average of only 3 degrees at Suchta Bay, in latitude 73° N. Even at St Petersburg, surrounded by large continents, it is only 7°.

The reason for this is simple. The changes in the solar altitude between sunrise and sunset are manifestly more marked where the sun rises higher in the sky than where its path is at a small inclination to the horizon all day, while at the Poles, where it takes a year to rise and set once, the daily variation entirely vanishes.

The diurnal range of the temperature of the air also diminishes with elevation above the sea-level.

Thus in the N.W. Himalaya, while the mean daily ranges at Mussourie and Ranikhet at 6000 feet above the sea are only 13° and 15° F., the ranges at Bareilly and Roorkee on the adjacent plains are 23° and 24° F. The reason is obvious if we remember that the heat received during the day is more absorbed by the denser air near sea-level than the rarer air on the mountains. Consequently, since the heat which falls on the mountain-top is more freely radiated back into space, the air over the mountains is less expanded than that over the adjacent plains.

During the day since the air over the latter expands upwards about 13 feet for every degree F by which the temperature of the entire air-mass up to 6000 feet rises. Meanwhile since the mountain cannot expand the air over it remains sensibly stationary. In consequence a downflow takes place towards the mountain somewhat like the sea-breeze towards a coast which brings with it the cooler temperature in the free air at the same level and so cools that on the mountain.

At night when the mountain which is a good radiator cools down rapidly and chills the air which lies on it, this air by reason of its increased density slides down the mountain side and its place being taken by the adjacent less cooled air, the temperature is again prevented from descending too low.

In valleys on the other hand even at high altitudes, the contrary conditions take place.

By day, owing to the greater perfection of the atmospheric enclosure, the sun's heat is more effective in warming up the lower stratum of air, while at night the chilled air from the surrounding mountain tops descends into the valley and increases the cold. Hence, at Leh in Thibet, which lies in a valley at 11,500 feet elevation the daily range is as high as 29 degrees. On a smaller scale it is practically recognised that frosts prevail more in valleys than on hill tops.

The atmosphere and the ocean thus exert a similar tendency in reducing temperature ranges, and the man who builds his house on a hill and so rises into the atmosphere, enjoys similar ad-

vantages to the one who takes up his residence on the sea-coast or an island. In both cases extremes of temperature are avoided.

The temperature is lowest as a rule on land shortly before sunrise. In tropical countries, such as India, where it occurs only just a few minutes before sunrise, it is often the only tolerable moment of the 24 hours.

The highest temperature occurs nearly everywhere on land between 2 and 3 P.M., but alters according to season.

The greatest changes in the times at which the daily temperature variation reaches its highest and lowest points are related to the position of the place as regards the ocean.

Put briefly, the drier and more inland or continentally the place is situated, the *later* will be the epochs, while out in the open ocean the mid-day maximum occurs soon after noon and the morning minimum as early as 4 A.M.

The *annual* range of temperature, or in other words the difference between the average temperatures of the hottest and coldest months, in contrast to the diurnal range, increases from the equator, where it is least, to the poles. It also increases with the distance from the coast. Thus while it is only $3\frac{1}{2}°$ at Colombo, it is 11° at Bombay, 21° at Calcutta, and from 30° to 40° in N.W. India.

The accompanying map, in which the lines of equal annual range of 5°, 10°, 20°, 30°, etc., are drawn, shews at a glance its general distribution over the earth, from which it is plain that while it is least over a broad belt surrounding the

equator, it reaches its highest values in the poleward centres of the continents.

In England the range of temperature between summer and winter is about 20 degrees. In Honolulu it is only 5 degrees, as near the

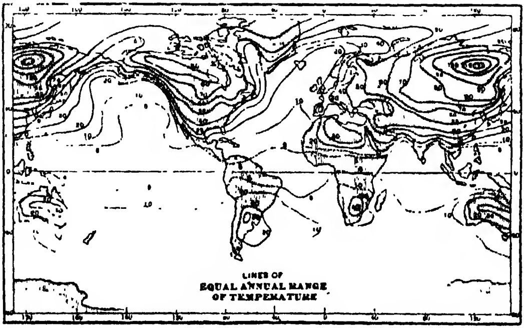


FIG. 9.

equator, while at Werkojansk in North Eastern Siberia it amounts to no less than 120 degrees. The man who boasts he can wear the same coat summer and winter through, would have to change his habits in that district. There are several remarkable features exhibited on this map. One is that in all the northern continents the position of the greatest annual temperature range is to the east of their geographical centres. This is chiefly owing to the influence of the warm currents which bathe their western shores and the accompanying wind currents which carry the moderating effect of the ocean over

a large part of their western interiors. Western Europe is peculiarly favoured in this respect.

Also the generally small range over the larger oceans which is due to the slow response of masses of water to the seasonal changes in the amount of solar heat falling on it, a point which has already been attended to. As a result, the ranges over the southern hemisphere which is mostly water are uniformly small. In New Zealand, for example, December and June differ by only 10 degrees.

Besides the diurnal and annual ranges of temperature it is found that there are slow periodic changes of a small amount in the mean temperatures of the year, in correspondence with the changes in the number and area of sunspots which recur about every eleven years. Whatever may be the exact cause, whether an increase or decrease of solar radiation corresponding to a great spot manifestation, the effects have been proved through the labours of Prof. Piazzi Smyth, Dr Stone, Dr Köppen of Hamburg, and Prof. Fritz of Zurich, to be visible in the temperature of the earth's atmosphere.

In years grouped round those of fewest spots, such as 1811, -23, -34, -43, -56, -67, -77, -88, the temperature is highest, and in those similarly grouped round those of most spots such as 1860, -71, -83, -93, it is lower than the average. The effect is most noticeable in the tropics. For example, in India, the difference between the temperature at the two epochs varies from 1 to 2 degrees on the mean of the year.

A similar periodic change is found to prevail in conditions which depend upon air temperature, such as fruit-harvests, vintages, rainfall, glacier extension, storms, cloud proportion, etc., while the late Professor Jevons endeavoured to shew that even commercial panics were brought about periodically through the medium of such indirect consequences.

Though there is much scepticism as to the quantity of the temperature effect being of such importance as to bring about panics through bad harvests, there is no doubt that the condition of the sun affects our atmosphere in some peculiar way not only in regard to temperature, but also magnetically, since the appearance of the aurora is admitted by those who dispute the heating effect to be closely connected with the presence of sunspots and other forms of solar disturbance.

This periodic oscillation of annual temperature does not of course involve any steady progressive change in the temperature of the atmosphere. In fact, when some years ago the people of Paris were temporarily afraid that their climate was changing, the astronomer Arago proved to their satisfaction, by a recourse to statistics, that the temperature of Paris had not sensibly changed for 100 years, and within *historical* periods there does not seem to be any evidence that the temperature anywhere is sensibly changing permanently one way or another.

We will now pass on to consider the circumstances that attend a local accession of heat over

land and water and the primary effects which it produces.

Beginning with any area on a small scale. Let fig. (10) represent a vertical section of the atmosphere and let the dotted times represent lines of equal barometric pressure beginning with 30 inches at the earth's surface, and let us suppose that the temperature of the central region is raised by a certain amount.

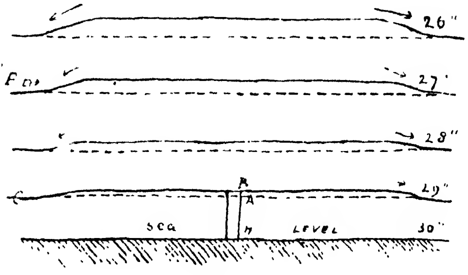


FIG. 10.

All the air thus warmed will expand. The column H.A. will expand to height H.B., and as each layer will expand all the way up, the surface of the top layer will be most raised. Consequently there will be a flow outwards of the raised up air down the slopes marked by the thick lines toward the neighbouring air of the same pressure, which, not being expanded, lies at a lower level.

The outflow will be greatest in the highest layer since it is the most raised (the increase is

denoted by the varying size of the arrows). Meanwhile the loss of air above will lessen the pressure on the earth's surface near the centre of the area. Consequently the surrounding air will flow in towards this centre chiefly in the lowest layer, and the action having once started will continue so long as the central area is more heated than the neighbourhood.

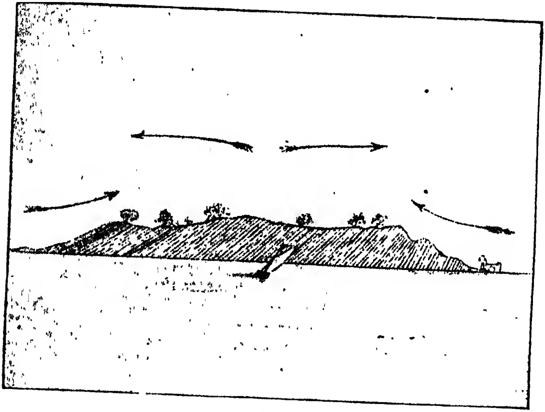


FIG. 11.

We have already noticed that where sun heat falls upon land it heats it up more readily than water. Therefore particularly in the case of an island lying in a tropical sea where the sun is powerful the above action takes place as in fig. (11) and we have the phenomenon known as the local sea breeze. When the sun disappears at

night the action is precisely reversed, and the air near the surface flows outwards as the land breeze, while above a certain height, which in local cases is often as low as 1000 feet, the air streams in over the rapidly cooling land.

After the action has once started things arrange themselves as in fig. (12) where the lower curved

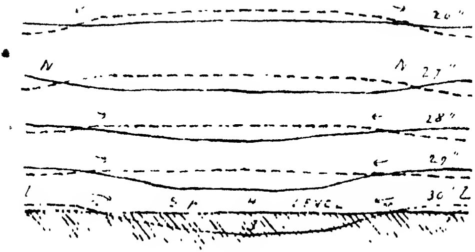


Fig. 12.

lines represent the barometric depression caus by the loss of air which has flowed outwards above, and where NN^1 represents where the tendency to flow in and out neutralise each other and there is a plane of no motion called sometimes the neutral plane.

The above action involves a certain amount of upward motion of the air over the central part of the heated area, and a corresponding downward motion over the surrounding cooler area, but these movements are evidently much smaller than the horizontal outflow and inflow. The same action also explains the origin ot the manifest monsoons of Asia and Australia, where in the summer season the air blows more or less towards a heated land

area, and in the winter from it towards the surrounding sea.

It also accounts in part for the annual changes in the barometric pressure over large areas, especially the low pressures in the middle of the larger continents like Asia and America during the summer, and the corresponding very high pressures at the opposite season.

Unless some such system of rise and overflow over the hotter areas and sinking and underflow over the cooler areas took place, the barometer would record a steady pressure over both areas, and if we ascended over the more heated area we should find the pressure greater than at the same level over the cooled area, because the air being more expanded vertically, there would be more top cover so to speak over our heads.

As a matter of fact, notwithstanding *the overflow which relieves this state of things*, the pressure at highly elevated stations like Leh (11,800 feet) north of Kashmir, rises until the beginning of May, and only falls very slightly in June and July. Consequently the lowering of pressure which appears so distinctly over Southern Asia in the summer is confined to the lower half (by mass) of the atmosphere, that is to say below 18,000 feet, at which level the pressure is 15 inches. Above this level there is more or less an outflow in the summer and an inflow in the winter.

A similar system of land and sea monsoonal circulation exists *everywhere*, only in high latitudes it is ordinarily masked by other motions of the air, introduced by the frequent passage of cyclones, and large travelling systems or waves

of high and low pressure. Even along Western Europe the winds blow more towards the land in summer and from it in the winter.

Where a small area on the land or sea is heated up above its neighbourhood we have the initial conditions for the formation of a disturbance of equilibrium. In hot countries where such a condition is more prevalent, there may arise a cyclone, tornado, whirlwind, or thunderstorm, under different conditions, which will be alluded to later on, but in order that there may be intense local action and a real '*courant ascendant*,' the air must not be merely gently lifted up and overflow, which is the only possible condition when it is dry, but it must be nearly saturated with vapour, in which case it will flow upwards so long as the lowest stratum continues to supply damp air. The part taken by temperature in causing these phenomena will be alluded to in a later chapter.

The present account of the temperature of the atmosphere would be incomplete if it omitted to notice the transfer of heat from one part of the earth to another.

So far we have merely examined the heat which falls locally or generally by means of the direct solar radiation.

The temperature over any region is however largely dependent on the heat brought to it by winds. When they come from the sea their temperature is modified by the influence of the ocean currents, warm or cold, over which they have travelled. When they come from the interior of a continent, they are usually hotter in

the summer and colder in the winter than the maritime regions towards which they advance.

Thus in summer our hottest wind in England is the south-east, and the same wind often accompanies our most severe frosts in the winter. The thermal effects of land winds therefore change with the season.

Sea winds, especially where they are connected with ocean currents, and blow with some degree of constancy, exercise a permanent influence upon the temperature of countries over which they prevail. The most marked warm sea winds are felt on Western Europe, the Pacific slope north of lat. 40°, and the eastern coast of South America.

These winds are not merely warm because they have accompanied streams of warm water, such as the Gulf stream of the Atlantic and the Japan stream of the Pacific, but because their cooling is retarded by the latent heat set free in the condensation of the vapour they bring from the humid tropics.

Several attempts have been made to measure the heat conveyed by both these streams. Dr Haughton of Dublin some years ago estimated that these two streams together carried one-third of the total heat received by the northern tropical zone towards the middle latitudes. Ferrel, however, has more recently shown that it is more probably one-sixth. As we have already seen, the effect on England is to raise the mean temperature nearly 10 degrees above what it would otherwise be. Norway is raised as much as 16 degrees, and Spitzbergen 19 degrees. On the other hand compensating cold currents and

the winds which blow off them depress the temperature of Eastern Canada, northern China, western South America, and western South Africa. Newfoundland is thus about 10 degrees colder than the normal for the latitude. The North China coast about 7 degrees colder, and even Honolulu, in the mid Pacific, has its temperature reduced 5 degrees by the return Japan stream cooled after losing its heat up north.

The general influence of the ocean currents in reducing the difference which would exist between the temperature at the equator and the poles, may be inferred from the fact, that according to Ferrel, if the surface of the earth were entirely dry land, and there were consequently no *transfer* of heat by oceanic or atmospheric currents, theoretical considerations shew that the temperature at the equator would stand at about 131° F., while that at the Pole would be 108° below Zero.

Observations, however, shew that the mean temperature day and night at the Equator is about 80° F., while that at the Pole is only 0° F. or Zero. Consequently the effect of the circulation of the ocean and the atmosphere, together is to depress the temperature at the Equator about 50 degrees and raise that at the Pole no less than 100 degrees, and in this manner render the earth generally fit for human habitation, since, if such extremes as those mentioned prevailed, man would have been forced to inhabit a very constricted zone in middle latitudes. In like manner were the earth deprived of its atmosphere the mean

temperature at the Equator would be 94 degrees below zero F., while that at the poles would be 328 degrees below zero F., and the mean temperature of the whole globe 138 degrees below zero F.,—a terrible frost. In fact, even if it were possible to do without air the human species as at present constituted would in such an event be quite unable to exist. With the protection of an atmosphere the average temperature of the earth, or more correctly of the lowest stratum of the atmosphere is about 60° F. which is regarded as the most delightful that can be enjoyed. *So much* do we owe to the invisible envelope of atmospheric air, which otherwise appears to constitute such a flimsy blanket between us and the terrible cold of stellar space.

Extreme local temperatures are due to the concurrence of accidental causes tending to raise or lower the temperature, such as the passage of storms, prevalence of winds from north or south, long continued clear weather, combined with those of more regular incidence. Extremely high temperatures will generally occur in these latitudes soon after noon in July and August, and extremely low ones early in the morning in January or February. Occasionally, however, the epochs are considerably displaced.

The highest temperatures on the earth usually occur in India, N. Africa, the Red Sea, the Persian Gulf, and Australia. Thus in the centre of the Sahara, 130 degrees has been recorded. At Jacobabad in the Sind desert, the temperature frequently rises over 120° F. and even in New South Wales,

120° and 121° have been recorded at Bourke and Deniliquin. In February 1896, a temperature of 108 degrees was recorded at Sydney, due to a remarkable prevalence of dry N. W. winds blowing over it from the interior.

Paris has only once reached 106 degrees and London has seldom recorded anything over 96°.

The coldest temperatures are found not at the poles themselves, where the water circulation tends to bring heat from the equator but in the north-east of Siberia and north-east America.

Werkojansk is the coldest place in the world. In January the mean temperature there is 55° F. below zero while all through the year the temperature is only 5 degrees above zero.

During arctic expeditions, the Alert and Discovery experienced 73 below zero, while Capt Nares once saw the thermometer descend to 84° F. below zero.

Of recent years, a great extension of our knowledge of the phenomena of the atmosphere has been made by the application of what is known as thermo-dynamics.

Prof. Bezold of Berlin, the late Prof. Ferrel of Washington, Dr Hann of Vienna, and others have cleared away much of the loose and misty reasonings which characterize the work of their predecessors, but the subject is too difficult and technical to be alluded to here. A few of the leading ideas however will be briefly touched upon when some of the particular atmospheric phenomena are being described further on.

CHAPTER V.

THE GENERAL CIRCULATION OF THE ATMOSPHERE.

THE 'Story of the Winds' is interesting and important enough to form the subject of a separate volume and within the compass of one which endeavours to cover the varied phenomena of the atmosphere generally, only the more salient points in connection with atmospheric motion can be reviewed. In these latter days, in spite of the old saying that "the wind bloweth where it listeth" and the manifest and apparently capricious changes which characterize its behaviour in these midway latitudes, we know that there exists an independent dominating scheme of general circulation between the poles and the equator. This scheme results from the action of nearly permanent differences of temperature between these points in combination with certain mechanical laws resulting from the shape of the earth and its rotation on its axis.

In former days many guesses were made more or less at variance with both facts and theory. Even Maury's fascinating attempt in 1855 to weave observation into a connected system, failed owing to the imperfect knowledge existing at that time of the winds of the entire globe as well as of the true laws which operated.

The earliest attempt at any rational scheme of accounting for the more obvious features of the general circulation appears to have been made in 1735 by Hadley.

The regularity of the 'trade winds' was then attracting the attention of scientists, and in a short paper in the Philosophical Transactions, Hadley advanced a theory to account for this which sounded so plausible, that for over a century it remained unquestioned.

Hadley's theory in brief was, that owing to the general difference of temperatures between the polar and equatorial regions, a motion of the air took place similar to that just described in the last chapter, in the lower strata towards the zone of greatest heat, while the easterly * direction of the trades was attributed to the fact that as the air continually arrived at parallels where the earth's surface moved faster eastwards than the part it had just left, it tended continually to lag behind in a westward direction, and so appear to blow partly *from* the east. Hence it became the north-east trade on the northern and the south-east trade on the southern side of the equator. Carried to its logical conclusions Hadley's theory would require the trades to blow all the way from the poles to the equator, the return current being confined almost entirely to the upper air.

Moreover the highest pressure as measured by the height of the mercury column in the barometer air balance, should be found at or near the poles.

As a matter of fact, however, it was found that neither of these circumstances took place.

The trades extended no further than latitudes 30 degrees N. and S. of the equator, the pressure

* From the East.

at the poles, especially the south pole was permanently lower than at the equator (about $\frac{4}{5}$ths of an inch of mercury) while the highest pressure was found to occupy two belts between 30° and 40° N. and S. of the equator.

Obviously therefore there was something radically wrong with Hadley's theory.

In 1856, Mr Ferrel afterwards Professor in the United States Weather bureau, tackled the subject and found out that Hadley had entirely overlooked the fact that the earth is a sphere.

In consequence his theory contained two serious errors, one of which was that only air moving north and south was deflected by the earth's rotation, while that moving in any other direction remained unchanged.

The only circumstances to which Hadley's theory could possibly apply would involve the supposition that the earth was a perfectly flat plane composed of separate planks parallel to a straight line equator. Also that these planks moved along with different speeds beginning with 1000 miles at the equator and gradually decreasing to about 850 miles at latitude 30°, manifestly a very different affair from a spherical surface like that of the earth.

Some few years before Ferrel approached the question, the eminent French mathematician Poisson in 1837 read a paper before the Paris Academy, in which he demonstrated that when a freely moving body passes over the earth's surface *in any direction*, the effect of the earth's rotation is to cause it to deviate (not lag) to

the right of its path in the northern hemisphere, and to the left in the southern.

Employing the same reasoning as Poisson, but applying it to *masses of air* instead of *solid bodies* Ferrel gradually built up a satisfactory explanation of the general circulation, and with the help of suitable modifications, applied the same principle to explain the leading features of cyclones and tornados.

In general, if a mass of air initially tends to move on a rotating sphere towards a certain point, impelled in the first instance by a difference of density or pressure, it tends to move continually to the right when looked at from a point above the N. pole of rotation and unless prevented from doing so by any extra force resisting such motion, would continue to deviate until it had turned through a complete circle thus fig. (13).

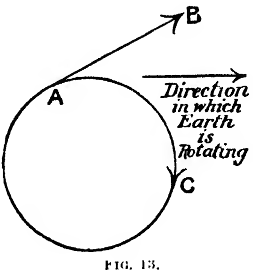


FIG. 13.

Suppose a particle of air at A starts to move towards B. Instead of moving in the straight line AB, it will tend to move in the curve AC, and if it is very near the pole it will eventually complete a circle* as above in 12 hours, the size de-

* In other latitudes the inertia curve as it is termed is more like the series of loops cut by a skater restricted between certain limits of latitude. At the equator it vanishes.

pending on its velocity. Thus for a speed of—

	Radius of inertia circle in miles.
20 miles an hour . .	77
10 ,, ,, . . .	38
5 ,, ,, . . .	19

We have the corresponding values of what is termed the curve of inertia.

Prof. Davis of Harvard has suggested a very pretty experiment which can be performed by any one who wishes to have visual evidence of the existence of this inertia curve.

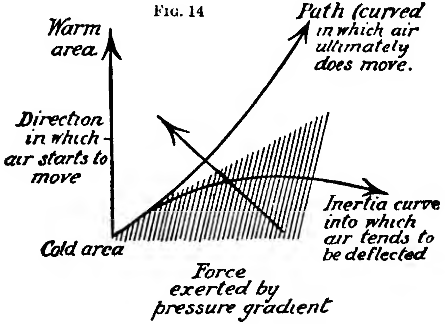
Take a small circular table, and lay a sheet of white paper over it. Then take a marble and dip it in ink and lay it near the centre of the table. Next tilt the table slightly so as to give the marble a slight motion towards the edge, and at the same time rotate the table about its centre. Then the marble will be found to trace out in ink a curved line on the paper which will fairly represent the inertia curve or the curve of successive deviations from a straight line by which the particle through its inertia (or laziness) is unable to accommodate itself to the varying motion of the parts over which it rolls.

In whatever direction the table is tilted the curve will still be traced out, the curvature sharpening with increased rotation of the table (analogous to increased latitude) and lessening with increased tilt by which the velocity of the particle is augmented.

This tendency of air to move to the right of its original direction of motion, is what really accounts for the development of those permanent

or rapidly changing differences of barometric pressure which accompany the large general or small particular air motions. A difference of temperature alone, for example, between the poles and equator, or between two neighbouring parts of the earth would cause a very slight alteration in the barometric pressures, but when the air begins to move in the direction of the lower pressure its tendency to push to the right, causes a squeezing and heaping up of air to the right of its path, and a corresponding stretching apart or lowering of density and pressure to its left, until the difference of pressures becomes great enough to prevent its further movement to the right and it moves in a path regulated by these joint tendencies, thus—

Fig. 14



A mass of air at the cold area will tend initially to move towards the less dense warm air, but once it starts it tends to move along the inertia curve. Eventually the high pressure

(denoted by the shading) of the heaped up air on this side exerts a force indicated by the arrow directed towards the increased low pressure to the left, and finally the air making a compromise moves along a line between the two, indicated by the direction, labelled 'Path' etc., so that instead of moving directly from high to low pressure it only partly moves towards the latter, keeping the high pressure to the right and the low pressure to the left of its path. In the southern hemisphere owing to the reversed point of view *right* becomes *left* and the high pressure would be to the left of the path and the low pressure to the right.

This diagram will be found to supply the explanation of the general relations between pressure and wind, especially if it is remembered that where, as on land and near the surface, the air is prevented by friction from moving with freedom, the back thrust in the opposite direction tends to make the ultimate path point more towards the low pressure, while at sea and at great altitudes, where friction is small, it moves almost at right angles to the line joining the central areas of high and low pressures, or in the technical language borrowed from engineering, at right angles to the direction of the barometric gradient.

Before alluding to Ferrel's explanation of the general circulation of air over the globe on these principles, let us see what this circulation really is like from observation.

In the two plates adjoining, figs. (15) and (16), in which the actually observed barometric pressures

and winds at two opposite seasons of the year are represented, it will be noticed that, overlooking minor features, there is a broad belt over the equator, over which the barometric pressure is about 29·80 inches, gradually rising on either side to two belts of high pressure, in latitude 30° in places reaching 30·2 inches, and generally about 0·2 inches higher than over the equator. Within this area, the trade winds blow throughout the year on each side of the equator, except over the North Indian Ocean, where in July they blow in towards an area of excessively low pressure and high temperature as the south-west monsoon of the Indian seas, which brings the rain, that has made India such a much more fertile and populous country than the neighbouring peninsula of Arabia. In the map fig. (20), p. 86, the monsoon winds are represented blowing over India during July. In January, the south-west winds disappear, and in the general chart it will be seen that their place is taken by Northerly or North-easterly winds, blowing down towards the equator, from the large area of high pressure which at this season spreads over the whole of north-eastern Asia.

On the polar sides of these bands or nuclei of high pressure, it will be observed that the winds blow more or less towards the poles, especially in the southern hemisphere.

The lines (isobars) on these maps, by which the changes in the distribution of the mean monthly barometric pressure is indicated, are similar to the contour lines or lines of equal elevation employed to represent the contour of

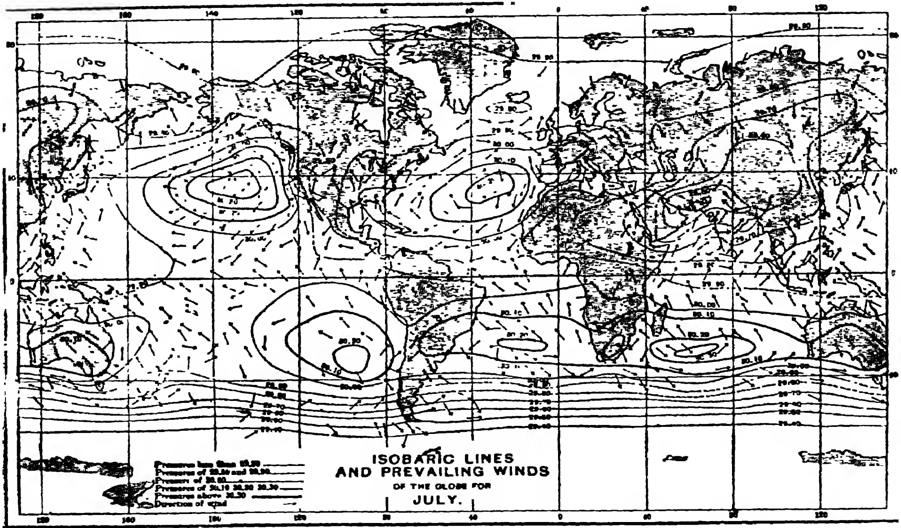


FIG. 15.

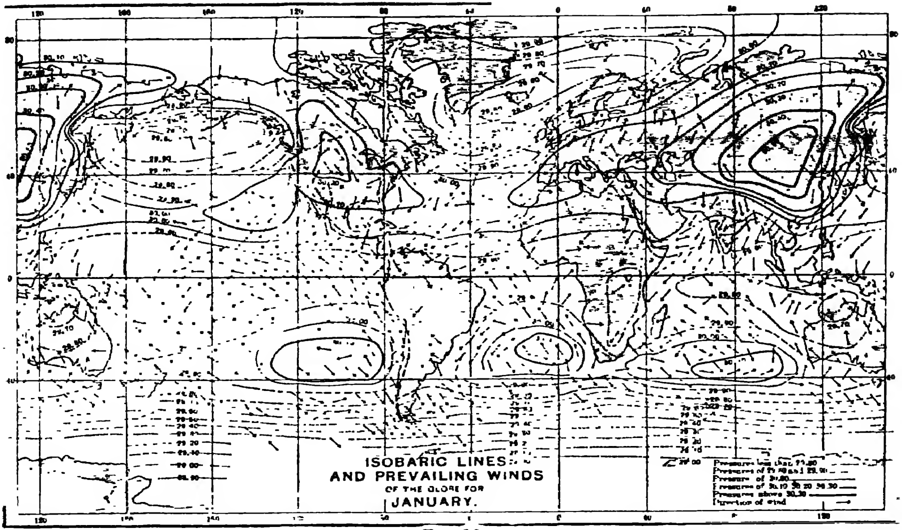
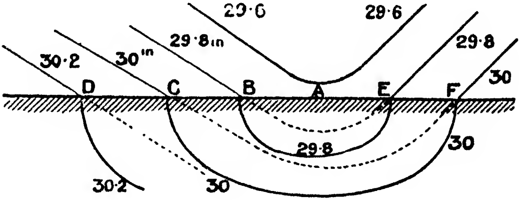

ISOBARIC LINES
AND PREVAILING WINDS
OF THE GLOBE FOR
JANUARY.

Fig. 16.

a hilly country. They do not necessarily represent real elevations or depressions of the atmosphere, because increased or decreased pressure is more due to a greater or less squeezing or density, than to a piling up of the atmosphere into absolute heaps and hollows, but since the effective results would be very much the same in either case, they may practically be considered as atmospheric contours. More correctly, they are the lines along which atmospheric contour surfaces intersect the earth's surface, the pressure over which at sea-level, (about 30 inches), lies half way up the atmospheric slope. The accompanying figure will render this clearer.



The sloping lines marked 30·2, 30, 29·8 etc., represent sections of the actual atmospheric isobars or pressure planes. *B*, *C*, *D*, points where these lines cut the earth's surface. The dotted continuations represent how the lines would run if the atmosphere took the place of the solid earth. The curved lines starting from *B* and *C* to *E* and *F*, denote the lines as they occur on the earth's surface or appear on a plane chart, when the contours curve round a central area *A*, where

the pressure in this case is about 29·7 inches. In considering the general circulation, *A* may be taken to represent the North or South Pole, in which case the diagram represents something like what actually takes place. When we are dealing with particular motions, *A* would correspond with the centre of a cyclone or travelling disturbance.

Returning to our story, it is plain from these maps, that the circulation of the atmosphere comprises a great deal more than a mere system of trade winds, blowing towards the equator.

Any theory that pretended to explain the entire system, would have to account for the prevailing high pressures about latitude 30° N. and S., and the poleward trend of the wind on the polar sides of these atmospheric sierras.

Ferrel, in his first paper in 1856, not only shewed that Hadley's theory was mathematically incorrect, but that Maury's fascinating scheme, put forward in his Physical Geography of the Sea, erred both in fact and the laws of physics.

Reversing the usual procedure by which laws are induced from observations and starting with a few fundamental principles, such as the law of deflection already noticed, he shewed that the high pressure belt about 30° and the system of poleward winds on the polar sides of it were necessary consequences of these principles.

Ferrel's final ideal chart of atmospheric circulation on the earth is represented by fig. (18) where the average motions near the surface are represented in plan in the shaded circle, and

in vertical section at the border, and though his explanation is a complicated piece of mathematical reasoning, the following represents the pith of it in simple language.

Assuming that the air over the equatorial zone is heated above that near the pole, it expands

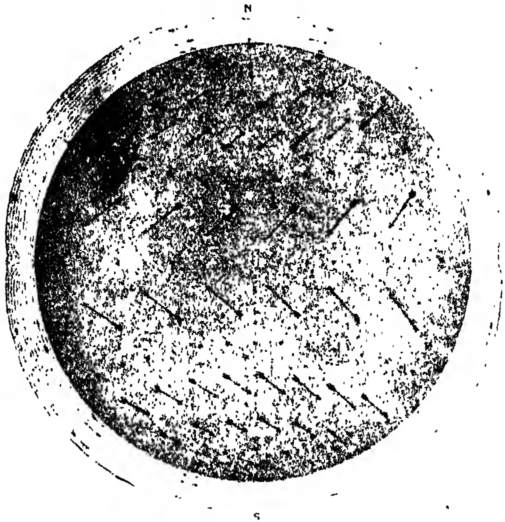


FIG. 18.

near the equator and contracts over the pole. Consequently the uplifted air over the equator tends to flow downhill as it were towards the poles and a corresponding flow near the surface takes place towards the equator. If the earth

did not rotate on its axis the upper air would flow direct to the pole then descend and return towards the equator along the surface. Since however the earth *does* rotate, the upper air is deflected in the northern hemisphere to the right (increasingly as it travels polewards) so much that were it not for the downward slope towards the pole, it would eventually deviate towards the equator. Consequently the pressure to the left of its path, *i.e.* towards the pole, is decreased and the pressure to the right is increased. This increases what would otherwise be an insignificant slope to what is actually observed. By the time this upper air has reached latitude 30° which divides the hemisphere into two equal areas* (though it is only a third of the actual distance on a meridian) it has descended to the surface and overpowers any tendency towards contrary motion in the air there, and the entire atmosphere tends to move bodily eastwards from thence to the pole.

Meanwhile the air near the surface between latitude 30° and the equator, moving towards the latter, deviates towards the west and heaps up pressure to its right and lowers the pressure to its left in the same way. Consequently on all accounts there is a tendency on the part of the air to heap up and increase in pressure about latitude 30° and to be reduced in density or pressure near the poles and the equator. Also since the air reaches a terminus at the poles and

* This most important fact is one of those things which is *not* as a rule taught at school, though it is of immense significance.

equator there will be calms at the surface at both these points. Moreover since on either side of latitude 30° or more correctly 35° the air moves along the surface in contrary directions, there will be an absence of prevailing winds over this region. These calms are known to exist, and owing to their proximity to the tropics used to be called the calms of Cancer and Capricorn.

The preceding explanation may be better

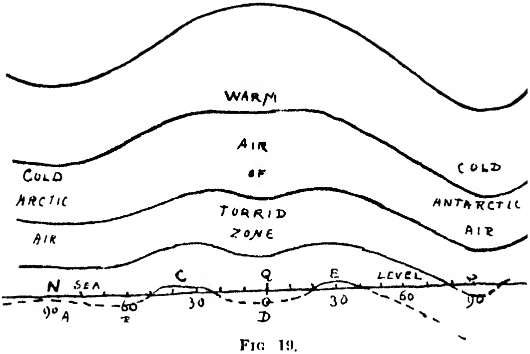


Fig. 19.

realised if we take a vertical section of the atmosphere along a meridian as it actually exists, and draw sections of the general planes of equal barometrical pressure as they exist by observation on the average at different levels between the equator and the poles as in fig. (19). The poles are at N. and S. and the equator is at Q.

The line A B C D E F represents a section of the general isobar of 30 inches at sea-level and shews two cols or hills at latituude 30°. Then as

we ascend these cols gradually disappear owing to the absence of the surface trades and therefore of the side pressure they create which keeps the opposite pressures exerted by the winds on their polar sides from pressing the air into one high pressure belt over the equator. As we ascend, therefore, these cols gradually coalesce into one central hill from which the air descends as a westerly upper current (blowing partly from the south in the northern hemisphere and from the north in the southern), into the two polar valleys on either side.

The depth of the atmospheric valleys of pressure below the top level of pressure at the surface of the earth converted into feet of air is found to be about 262 feet at the equator, about 320 feet at the north pole, and 640 feet at the south pole.

At a height of 30,000 feet above the surface the north polar valley is 2,800 feet and the south polar valley 3,100 feet below the mean level. The height at which the equatorial valley disappears varies from 8,000 to 12,000 feet. Above this level there is a downward slope all the way to the arctic and antarctic circles and possibly to the poles themselves.

Viewed as a whole, the general circulation of the air according to Ferrel, may be considered as consisting of two huge atmospheric whirls, or, as they are technically termed cyclones, with the poles as centres, in which the air rotates in each hemisphere in the direction of axial rotation. On the equatorial side of each of these whirls, a belt occurs in which the motion of the air is contrary to that of axial rotation. These are the

trade wind belts. Between these two areas the air is heaped up into two zones of high pressure, reaching their highest values in the northern hemisphere about latitude 35° and in the southern about latitude 30°.

Since this system was established by Ferrel, Dr Werner Siemens, von Helmholtz, Herr Möller, Professor Oberbeck, Dr Sprung and others have developed the theory by the aid of more modern refined methods and closer reasoning, but their conclusions are substantially the same as those deduced by Ferrel, and the above sketch represents as far as can be attempted in a work like the present the modern theory of the general circulation of the atmosphere.

The most noticeable permanent modification from the ideal condition of things is afforded by the exceedingly low pressure round the south pole and the strong north-west winds which prevail south of the Atlantic, Indian, and Pacific Oceans, and which enabled Australian clippers in the old days to make passages of fabulous rapidity. This is due to the fact that the southern hemisphere is chiefly covered by water which, by exerting less friction on the air than land, allows its motions to occur with greater freedom. In consequence of this the Antarctic barometric depression is more developed and more symmetrical than the northern. For example the pressure on the latitude corresponding to our Antipodes is permanently $\frac{3}{10}$ths of an inch below what we experience, while the wind velocity is three or four times as great.

The seasonal changes and migrations as the

sun moves north and south are scarcely noticeable in the southern hemisphere for the same reason. In July the pressure over the tropical* belt as we may term it, is slightly increased, and the belt lies a little further south than in January. In the northern hemisphere on the other hand, the seasonal changes are far more conspicuous.

The high pressure nuclei which in July lie on the eastern sides of the Pacific and Atlantic oceans have by January shifted on to the continents of America and Asia, while the low pressures, which in July occupied the middle parts of North America and the centre of Africo-Asiatic continent, (the centre lying almost exactly over the Persian Gulf which is the geographical land centre) in January lie over the North Pacific and North Atlantic. Meanwhile the equatorial low pressure belt, or barometric equator as it may be termed, which in January is confined between its ideal equatorial limits, in July runs up into the northern continents and in Africo-Asia in particular, may be said to lie entirely over the land surface, where it causes the Monsoon as in figure (20). The relation of these extensive migrations to the effect of seasonal changes in solar heat on the air lying over land and water surfaces is obvious.

The result of these large transfers of air and air pressure north and south, and between the oceans and the continents, is to cause what is termed the annual variation of the barometric

* The term tropical is here used to signify *on* or near the tropics or turning points and not to the entire space between them as is usually the case.

pressure at any single place on the earth. This annual variation reaching its extremes generally in January and July, will be found to be largest in the centres of continents such as Asia where the barometric shift is greatest, and least on the

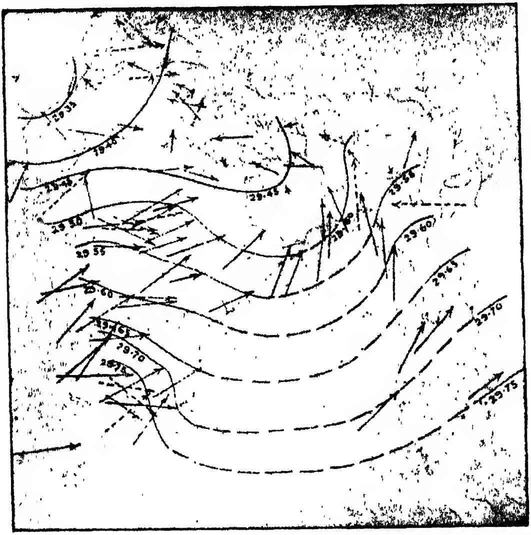


FIG. 20.

coasts which are the axes of the annual pressure see-saw between the oceans and the continents.

In England the change is small, amounting to about 0.12 inches between January and July.

In India, it increases from 0·26 inches in

Bengal to 0·62 inches in the Punjab, while over Siberia and central Asia it reaches about 1 inch.

The mean pressure over the whole earth is 29·89 inches. In the northern hemisphere the mean pressure for January is 29·99, and for July 29·87. For the southern hemisphere the pressures in the same months are 29·79 and 29·91. From this it is evident that there is a much greater difference between the quantity of air over the two hemispheres in the northern winter in January than in the southern winter in July.

This difference in favour of the northern hemisphere really means that owing to the greater cooling and contraction over the northern land area in the winter 32,000,000 tons of air have shifted over to supply the defect. There is no protective tariff placed upon this valuable import from the southern hemisphere.

A seasonal shift of the general wind system of the lower strata occurs like that in the barometric pressures, as the sun shifts north and south.

The shift of the sun in latitude is 47°, but the wind systems only shift from 5° to 8° on the northern, and from 3° to 4° on the southern side of the equator. The accompanying diagram fig. (21) gives an idea of the effect of the shift. The central belt (sub-equatorial) represents the district which is alternately subject to the doldrums or equatorial calms, formerly the bane of sailors, and the attendant bordering trades as they oscillate north and south.

The width of this belt varies from 350 miles in the Atlantic to 200 in the Pacific and lies on the north side of the equator all through the year, owing to the fact that the system of circulation in the southern hemisphere and round the South pole, owing to smaller friction, is so much more powerful than that in the northern

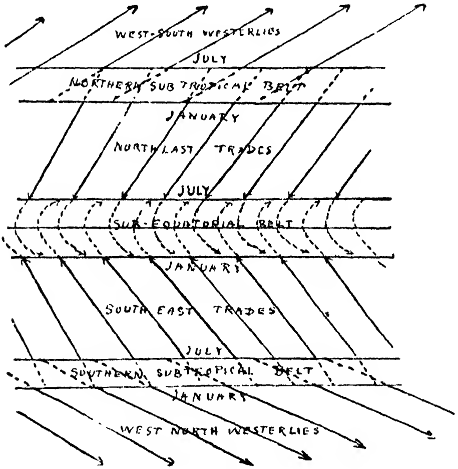


FIG. 21.

that the pressure belts on that side are all pushed northwards.

The sub-tropical belts, as the calms of Cancer and Capricorn are now termed, are similarly the alternate arena of westerlies, trades, and intervening calms.

So far, we have mostly considered the general circulation with respect to the motion of the atmosphere near the surface. The Upper current which blows all the way from the equator to the poles, is usually termed the Anti-trade in the tropics, because it overlies and blows in the contrary direction to the latter from the south-west on the northern, and from the north-west on the southern side of the wind equator. In the equatorial zone its lowest limit is about 10,000 feet, and as we proceed polewards, this limit descends so that along the range of the Himalaya in the winter season, this upper current descends to within 2000 or 3000 feet above the sea.

On the Peak of Teneriffe, Prof. Piazzi Smyth, when he was conducting astronomical observations there in 1860, was able to walk up through the north-east trade wind and find the south-west upper current blowing continuously at his station at Alta Vista, 10,000 feet up the mountain side.

In like manner the smoke of lofty volcanoes such as Cotopaxi 18,000 feet, and Coseguina lying in the trade wind zone have been observed to blow from the west, contrary to the surface wind.

Nearer the poles about latitude 35° to 40° the lower edge of this upper current touches the earth, and its lower half breaks up into what Prof. Helmholtz terms vortices. In plain language it separates into irregular currents which form the cyclonic storms which are so

prevalent in high latitudes on either side of the equator. Meanwhile the upper part of the current, except where it is affected by local disturbances or whirls, continues to move generally from the south-west or north-west. Its motion is determined by observation of the high clouds which float at an average elevation, according to the most recent measurements, of about 27,000 feet.

The general circulation of the atmosphere and its seasonal shifts is intimately bound up with the general distribution of the rainfall of the world, and the permanent occurrence and seasonal shifting of zones of drought and rain. Locally, rain is due, especially in high latitudes, to the passage of cyclonic storms, but in the equatorial and trade wind zones, the rainy season is almost entirely determined by the shift of the doldrums.

Without at present going into the question of how rain is produced in all cases, it is easy to see why the central belt of equatorial calms is an area of constant cloud and rain. For the air there, supplied with vapour by the inflowing trades on either side, is constantly rising up to higher and colder levels, where it cannot contain so much vapour as at sea-level. The surplus therefore condenses first into cloud, and then into raindrops which fall back to the sea-level. On the equator, as at Singapore, it rains everyday. As the doldrum belt oscillates north or south, it may give rise to one rainy and dry season, or in some cases to two, thus,

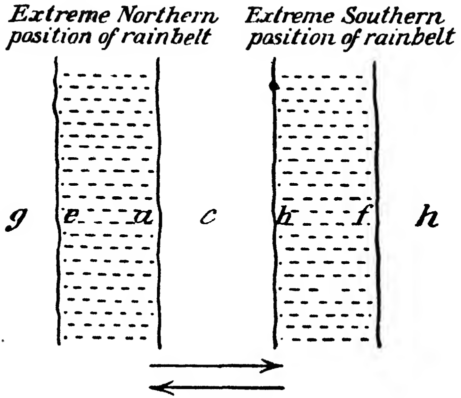


FIG. 22.

If a place is situated at a or b, just within the edge of the rainbelt at its extreme positions, it is within the belt during half of the year about, and without it the other half. Consequently, it has a rainy season for six months, and a dry season for about six months. This is the case at Panama, where it rains from May to November, and is comparatively dry during the remaining months. Similar equal periods occur in Bengal, the Nile Basin, and Northern Australia. When a place is situated at e or f, nearer the outer edge of the rainbelt in its extreme position, the rainy season is shorter, and the dry season longer. The Punjab, Upper Burmah, northern Mexico, and northern Central Australia are regions which underly the rain-belt for only three months of the year, and if, as in the year 1896

some irregularity occurs in the arrival of the belt, the rainy season may be so short as to cause drought and famine.

Places such as g and h, lying outside the influence of the equatorial rainbelt altogether, would be rainless except for the extension equatorwards of the system of polar winds, which sometimes descends as far south as latitude 35° in the winter. Between latitude 35° and latitude 20° N. and S., except where as in India, monsoons blow from the equator, or along coast lines, no regular rainfall belt arrives, and the dry desert zones of the earth tend to form.

The dry regions of California, Arizona, and Colorado in North America, the great Sahara and Nubian deserts of North Africa, and the Arabian and Persian dry areas all occur between these limits in the northern hemisphere.

In the Southern hemisphere within the same parallels are the dry regions of the Argentine and Eastern Patagonia, a large dry region in South Africa and one comprising the whole interior of Australia. These areas coincide with the belts of high atmospheric pressure and may be said to *suffer* from permanent fine weather.

Places at c between the two positions of the equatorial rainbelt, experience two short dry seasons alternated by two short seasons of rainfall. Such are Ceylon and southern India, Colombia in South America, parts of the Nile basin and Java.

In the latitudes between 35 degrees and the poles, the seasonal rains are entirely regulated

by the seasonal shifts in the polar system of general winds.

Here again, owing to the shift in latitude of a principal single rain belt corresponding to the seasonal shift of the sun, some places in the middle of the area between its extreme limits undergo two rainy and two dry periods. In South Europe, for example, the rain falls mostly in the winter, because the system of winds circling round the pole reaches its furthest extension towards the equator at that season. In middle Europe, the rains fall chiefly in spring and autumn as the belt moves north and returns, and in Northern Europe they fall chiefly in the summer.

The general circulation of the atmosphere not only determines the prevalent direction of the winds on the surface and in the upper regions, but also exercises a very large influence upon their average velocity.

The practical importance of possessing a knowledge of the general velocity of motion of the air above the earth's surface is evident when we touch upon the subject of ballooning or the coming flight of man.

When man is able to circumnavigate the ocean of air with the same ease that he sails across the ocean of water he will require to possess as accurate a knowledge of atmography (to invent a title) as he does at present of hydrography. We have at present a hydrographer to the admiralty, and we shall then require the services of one who will tell us all about the movements and conditions of the air, not only at sea-level,

but in the upper regions whither it will be necessary to ascend in order to cross mountain chains.

From the theory of circulation as developed by Ferrel and Oberbeck, it appears that the surface wind ought to reach its greatest average velocity about latitude 50°, and diminish thence both towards the poles on the one side and towards the equator on the other. As a matter of observation this appears to be the case.

Taking an average of the winds throughout the year, the late Prof. Loomis found the following average values for the wind in typical latitudes:—

	Mean velocity of wind in miles per hour.
Europe	10·3
United States . . .	9·5
Southern Asia . . .	6·5
West Indies . .	6·2

In England the average surface wind is nearer 12 miles an hour. Like other elements the surface wind varies with distance from the sea, time of year, and time of day.

The movements of the air are much affected by the nature of the surface over which it passes.

It moves faster over water than over land, and faster over flat bare land than where it is hilly or covered with forest. In the interior of continents it is much more sluggish than near the coasts or out at sea.

Thus in India, the wind velocity diminishes as we leave the coast in the following manner :—

	Towns.	Velocity of wind in miles per diem.
On coast	Bombay . .	408
	Kurrachee . .	497
About 100 miles from sea	Calcutta . .	123
	Dacca . .	147
500 miles from sea	Allahabad . .	91
800 miles from sea	Roorkee . .	65

Again, while the velocity over Europe is 10 miles an hour, it is as much as 29 miles an hour over the North Atlantic

Everyone is aware of the great amount of wind experienced even in summer when crossing the Channel as compared with that felt on shore.

A similar difference of velocity is observed as we ascend from the earth's surface.

This is partly due to the decrease of friction and partly to the increased slope down which the upper air raised by the equatorial heat tends to flow towards the poles.

Near the surface and for the first 50 or 100 feet the increased velocity with height is entirely due to the diminished friction encountered by the air against the roughness of the surface, trees, houses, and other obstacles. After that the retardation of the lower layers is communicated to the upper ones in a gradually decreasing scale by means of the friction of

the air molecules against each other, somewhat as a spoon passed through treacle or honey drags some of the surrounding mass along besides what it pushes directly in front of it.

This property of the particles of a gas is termed viscosity, owing to its similarity to the visible behaviour of what is termed a viscous liquid like melted glass.

Such resistance which neighbouring portions of gas offer to one another's motion is due, on the Kinetic theory of gases, to the collisions which are constantly taking place between the rapidly oscillating molecules.

A good parallel is offered by a crowd of persons all moving along a road in the same general direction towards some common point of interest. If everyone moved at the same pace in parallel lines, the speed of the crowd would be the same as that of any individual person, but owing to the fact that some persons cannot walk so quickly as others, some stop to look at the shop windows, others walk crookedly and jostle their neighbours, while some walk back against the crowd because they have left something behind them, the average speed of the crowd is sensibly reduced below that of the quickest walkers, though it still remains above that of the slowest.

In like manner if two streams of persons, one moving faster than the other, join together and personal interchanges take place between them, the persons who walk across from the slower stream into the quicker one tend to retard its average pace. Those on the contrary who move

across from the quicker stream into the slower one tend to accelerate its average pace.

In a similar manner, adjacent strata of the atmosphere tend to equalise each other's speed on a small scale by interchange of molecules, and where large masses intermingle, as in the general circulation, by interchange of masses, moving with different average speeds.

It is by this internal friction between intermingling air masses in addition to that experienced by the friction of the lowest layer against the earth, which is gradually communicated to those above, that the atmosphere does not assume unheard-of velocities and storms are not more violent than they are. The latter alone would not be enough.

Helmholtz, for example, has calculated that if the atmosphere generally started moving over the earth with a certain average velocity, say of 20 miles an hour, it would take no less than 42,747 years to reduce this to 10 miles an hour by the action of friction with the ground.

The first experiments to find the increase of velocity of the air with the height above the ground were undertaken by Mr T. Stevenson of Edinburgh, who attached anemometers of the Robinson pattern at different heights on a 50-foot pole. Here the retarding effect of the ground was found to rapidly diminish in the first 15 feet. Above this the rate decreased. For building and engineering purposes it is best to make experiments in the locality and trust to no formula, since the rule alters rapidly up to the first 100 feet.

Beyond this and up to 1800 feet experiments

conducted by the author in 1883-5, under a grant from the Royal Society, resulted in establishing the fact that the average velocity at 1600 feet is just double the velocity at 100 feet. Above the former height the rate appears to increase, if we are to judge from the observations of the clouds made at Blue Hill Observatory, near Boston, U.S.A. Mr Clayton's recent observations there of the movements of the different cloud strata reduced to English measure give the following results throughout the year :—

Cloud level	Height in feet.	Average speed in miles per hour.
Stratus . .	1,676	19
Cumulus .	5,326	24
Alto-cumulus	12,724	34
Cirro-cumulus	21,888	71
Cirrus . .	29,317	78

The rule in this case may be simply remembered thus. For every 1000 feet of ascent add on about 2 miles an hour to the velocity of motion.

In winter the speeds are twice as large at the upper levels as in summer. For the winter half year the speed of the cirrus is as much as 96 miles an hour, considerably faster than our express trains travel at present.

In Europe the velocities appear to increase less rapidly, but are still large when compared with those at the surface.

An average of closely concordant results, obtained by Dr Vettin of Berlin and Hagstrom and Dr Ekholm of Upsala in Sweden, make the velocities at 4300 and 22,000 feet about 19 and 38 miles per hour respectively. Here the rule

gives about 1 mile per hour for each 1000 feet of elevation, which is probably nearer the mark for Europe generally.

This great increase of velocity of the average motion of the aerial ocean as we rise above the surface is scarcely realised by us tiny mortals who dwell mostly at its base.

The loftiest building is scarce 1000 feet above the ground, while the loftiest inhabited place is but half-way through the mass and probably a twentieth of the actual height of the atmosphere. The great velocity often attained by balloons is thus readily explained.

At the same time it is equally plain that no navigable balloon will ever be able to stem the currents above 5000 feet, while flying machines would do well to travel *with* the wind above this elevation. In fact they may eventually utilise these rapid currents much in the same way as the Australian clippers formerly utilised the brave north-west wind which blows so powerfully round the watery expanse of the southern ocean.

One very curious result of this great motion at high altitudes has been recently pointed out by Herr Möller, a German engineer. The energy of the motion of the air or the power it possesses of performing work is proportional to its speed and mass. Möller has thus calculated that the energy of the upper half of the atmosphere—*i.e.*, the half above 16,000 feet, is no less than six times the energy possessed by the lower half. **Of the whole of this inconceivably enormous store of energy we at present utilise a minute proportion in sailing ships and driving windmills. The rest is completely wasted.**

CHAPTER VI.

THE LAWS WHICH RULE THE ATMOSPHERE.

The story of the earth is for the most part a chapter of ancient history. The story of the atmosphere is a tale of to-day, and even of to-morrow. When we have opened up the earth's crust to view we can trace the operation of past changes in the physical and chemical nature and position of the different rocks. All the atmospheric motions and changes, on the other hand, are going on before our eyes. Every action, moreover, is subject to the *reign of law.* The chaos which at first sight appears to surround the infinite complexity of atmospheric phenomena is reduced to harmony and order in proportion as we learn the true laws which operate in the grand laboratory of Nature. We have been a long time learning our lesson, and we are only now beginning to rise from superstitions and guesses to those intellectual "Delectable mountains" whence we may, even though it be "through a glass darkly," snatch a glimpse of the true character of the mysteries of our wonderful atmosphere.

The earth is a symbol of rest, stability, and permanence. The atmosphere, on the other hand, is in ceaseless motion and constant activity, under the influence of the heat of the sun, the cold of space, the rotation of the earth, and the changes of the seasons, as it moves in its orbit round the sun. Physicists working in their laboratories have discovered that certain laws

are obeyed by air in common with other gases, and it is only when we know these laws that we can interpret the phenomena which are daily and hourly observed in the sky and air around us. One of the first laws relating to the atmosphere was discovered by Dr Boyle, the celebrated Glasgow chemist, and Marriotte of France, and is usually called Boyle and Marriotte's law. This law states that if a volume of gas (which is elastic and compressible), confined within certain limits, such as an elastic bag, is subjected to compression, its pressure increases in the same proportion as its volume decreases. Thus, if 6 cubic feet of air at the ordinary atmospheric pressure were squeezed together until they occupied only 3 feet, the pressure or resistance of the air would rise to that of two atmospheres; and if a mercury barometer, at first marking 30 inches, were placed within the containing vessel, the column of mercury would at the end of the experiment rise to a height of 60 inches.

Human beings, when subjected to moral pressure, frequently exhibit similar characteristics, though their resistance cannot be measured on a moral barometer. In the free atmosphere such an ideal case seldom occurs, since the air generally finds some escape from complete compression by expansion or motion in various directions.

One immediate result of this law is the great density of the lower strata of the atmosphere, due to the compression to which they are subjected by the weight of the overlying layers. In like manner the rarity of the upper air is due to

its smaller compression. Also, when any mass of air is *forced* upwards, it comes under gradually decreasing pressure, and consequently by Boyle's law it *expands*. Conversely, if it is *forced* downwards, it *contracts* owing to the increasing pressure.

It is important to notice the distinction between cases where the air is *forced* upwards and where it ascends by reason of an expansion already effected before it starts, by the action of heat. In the former case it stops when the forcing agency stops. In the latter it rises to the level where the air all round is equally expanded, and therefore of the same density.

The former case occurs in Nature, where a wind blows athwart an abrupt chain of mountains, which force the air up their sides. The latter occurs wherever air is locally heated above or cooled below that surrounding it.

When, instead of being compressed, the air is heated within a confined vessel, its pressure increases in direct proportion to its rise in temperature (when reckoned from an absolute zero 461° below zero Fahr.). If when heated it is allowed to expand freely (that is to say, still confined by ordinary atmospheric pressure) it expands or increases in volume in like proportion. This is called the law of Charles or Gay-Lussac.

A third law which is really the converse of this may, for convenience, be termed Poisson's law, and asserts that, if air is *suddenly* compressed it rises proportionately in temperature, and if suddenly *allowed* to expand, it falls in temperature. The suddenness is only necessary in order

that the heat engendered may not have time to escape before it can be detected. These three laws, in combination with a few special characteristics displayed by water vapour, explain all the varieties of atmospheric phenomena primarily

Photo by *Negretti and Zambra*

FIG. 23.—"AFTER THE STORM.
From the Croix de fer Switzerland, 7000 feet above sea-level.

due to the action of heat and cold, such as wind, storms, clouds, rain.

These laws are really only variations of one grand principle which applies to everything in the Universe—viz., what is termed the "conservation of energy." Thus, to take a single example, when a bullet hits a target it gets quite hot, and

the heat that is thus generated is the exact equivalent of the motion that is lost.

Heat, as we have learnt, is "a mode of motion." It is, in fact, a motion of the small atoms or molecules that make up a body instead of a motion of the body itself.

According to the modern theory of gases, which applies equally to a mixture of gases such as air, the tiny atoms or molecules which compose them are in a state of constant motion backwards and forwards, kicking, as it were, against each other, and against anything that obstructs their freedom to move. The pressure exerted by a gas on its neighbourhood, whether this is solid, liquid, or gas, is measured by the number of kicks or impacts which its atoms perform in a given time.

If the gas contained within a bag (say) is compressed, the paths of the atoms are shortened, and, in consequence, the number of impacts with each other and against the sides of the bag is increased—*i.e.*, the pressure increases. That is Boyle's law.

In like manner, if, without compression, the temperature of the gas is raised, the speed of the movements is increased. (Molecular speed *is* heat.) Therefore, the *effect* in this case is just the same as when the gas was compressed and the paths were shortened—viz., an increased number of impacts or kicks, and therefore increased pressure. That is Charles's law.

When the gas is suddenly compressed, the atoms have been pushed towards each other, and their speed has therefore been increased by this

push. Consequently, a rise of temperature takes place. This is Poisson's law.

In all these cases, no energy is lost or created. It is simply a transformation of motion into different "modes," from which it can be retransformed without sensible loss, though it is easier to transform motion into heat than heat into motion. Dr Joule, of Manchester, was the first to determine the exact equivalence between what we term motion and heat. His corrected law may be stated thus:

When a pound weight falling through 783 *feet is arrested, as much heat will be developed as will raise one pound of water one degree above absolute zero.*[1]

The converse is equally true. Here we see the true cause of the marvellous manifestations of energy in the movements of the atmosphere, the devastating hurricanes which overturn buildings and destroy ships, and the terrible tornados of America which have been known to carry solid objects like wooden church spires a distance of 15 miles and kill hundreds of people in the space of a few minutes. They are all due to the heat of the sun, which is converted into motion on the above scale.

Charles's law, by which air expands by heat, and Poisson's, by which it cools by expansion under diminished pressure, have a very important bearing on the formation of clouds, rain, thunderstorms, tornados and tropical cyclones.

When a mass of dry air, or air only containing a small proportion of vapour, rises, it cools at the rate of 1° F. for every 183 feet it

[1] (*i.e.*, 461° below zero Fahr.)

ascends. This would be about 1·6° in 300 feet, or about 5·2° in 1000 feet.

The rate, however, at which the air is found by observation to *remain* cooler as we ascend in the atmosphere is much slower than this. Consequently, if dry air is warmed up until it expands and gets lighter than the surrounding air, it cannot rise very far before it is cooled by ascent, down to the temperature and density of the air around it at the same level, when it is bound to stop.

When, however, air contains as much vapour as it can hold invisibly, or is said to be saturated, the case is different. As it ascends and cools, the vapour condenses into cloud and finally falls out as rain and at the same time gives out the heat which it absorbed in the *act of conversion* from water into vapour. This heat, which is *latent* so long as it is vapour, becomes *patent* when it condenses and retards the cooling of such a mass of air so much that under ordinary conditions of temperature and pressure in these latitudes (barometer 30 inches, thermometer 62°), it only cools $\frac{3}{4}$ths of a degree Fahr. in ascending 300 feet. An ascending current of air saturated with vapour once started, therefore, could go on ascending until nearly all the vapour had fallen out of it, or until it had risen into very lofty and cold regions of the atmosphere.

Air saturated with vapour is thus essential to the formation of clouds, especially cumulus clouds, like that in our frontispiece, and of upward currents generally, which are the chief cause of local storms. Diffusion by which one

gas tends to work its way through another plays an important rôle in atmospheric economy. Were it not for diffusion the heavier gases would all lie near the surface and the lighter near the top, and we should all be poisoned off by even the small amount of carbonic acid there is.

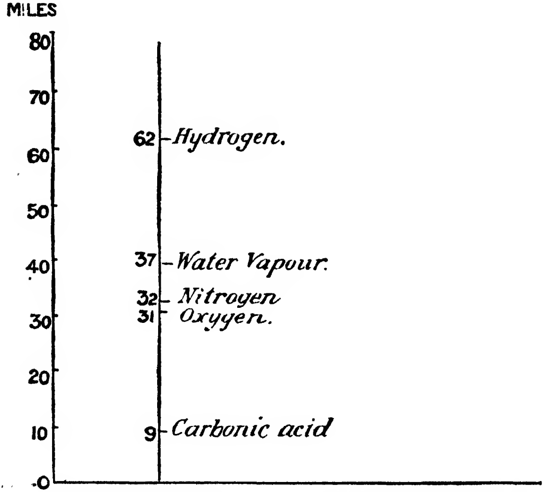


FIG. 24.—DIFFUSIVE LIMITS OF THE COMPONENT GASES OF THE ATMOSPHERE.

Some years ago the great chemist Dalton founded the law of gaseous pressure, and deduced that of diffusion from it, but it has since been found that though his conclusions were fairly correct, they are not due to the causes he alleged. The rule is that the lighter the gas the

more rapidly it tends to wander through its neighbours, and the tendency is for each gas to behave as though its neighbours were not in existence. Thus, the *tendency* is for the component gases of the atmosphere to take up positions in which they would exist as separate atmospheres up to the limits in miles indicated opposite each in the adjoining diagram.

This ideal final arrangement never takes place owing to the constant motion, but since all the gases diffuse upwards as well as downwards it is quite possible that some of the hydrogen and lighter gases have diffused upwards until they have got beyond the power of recall by gravitation.

Long before the water vapour has reached 37 miles, a great deal is lost by being condensed into rain. At a height of 9 miles above the surface, for example, the actual amount of vapour present is only $\frac{1}{30}$th of what would exist if it were incondensible.

The laws which determine the passage of the sun's heat and light through the atmosphere present problems which are even yet only partially solved, partly because light and heat are made up of a variety of wave movements in that wonderful medium which pervades all space termed aether, and partly because the conditions in the atmosphere can never be exactly imitated in the laboratory.

However, this much is known. Ordinary white light from the sun when passed through a prism is found to be made up of a variety of coloured rays ranging from violet to red. The visible violet rays are made up of the smallest

waves, about ·00001 in. in length, and the visible red rays of waves about ·00003 in. Beyond these visible rays are invisible ones which affect the atmosphere and earth, and whose existence can be proved by photography. The rays towards the red end produce more heat than light, and those towards the violet end more light than heat. The general action of the atmosphere on these rays from the sun is twofold. In passing through it they are partly absorbed and partly scattered. The blue and violet rays are most affected, and the red least. In fact, as Prof. Langley has pointed out, so much of the blue rays are filtered out by the atmosphere that if we could see the sun as he appears at the outside of our atmosphere he would be *blue* instead of white.

The absorption particularly of the heat rays has been shown by the late Prof. Tyndall to be mainly effected by the water-vapour present in the atmosphere, while the scattering is effected by the fine particles of dust and frozen vapour.

The red colours at sunset are due to the fact that the sun's rays, before they reach our eyes in this position, pass through a thickness of atmosphere about 900 miles instead of 50 miles when overhead. The blue rays, in consequence, are nearly all filtered out, and nothing is left but the longer waves at the red end of the prismatic spectrum. The red colour of the sun when seen through a fog is due to a like excess of absorption and scattering of blue rays by the particles of fog.

Similarly, the blue colour of the sky when the

sun is high up in the heavens is explained by Lord Rayleigh to be due to these missing blue rays. Scattered mostly at right angles to the direction of the sun's rays, these spurned rays reach us from all parts of the sky, and shew up blue against what would, in their absence, be the black background of space.

When the luminous rays from the sun pass through the air, they heat the dry part of it very little. The absorption is mainly effected by the small but valuable vapour constituent, which Prof. Hill estimates as being 764 times as effective as dry air. The remaining rays on reaching the earth are changed into invisible heat rays, which possess the peculiar property of being unable to repenetrate the atmosphere. Trapped thus like lobsters in a basket, they expend their energy, first upon the earth's surface and then upon the adjacent air. The atmosphere, in fact, acts like the glass in a greenhouse, which lets the luminous rays in and prevents their escape when they have become converted into dark heat.

The upper parts of the atmosphere would thus remain colder than they are, were it not for the *conveyance* (convection is the technical word) of the heat from the lower strata to the upper regions—in other words, from the ground floor to the attics. This convection plays such an important part in the atmospheric economy, and in the formation of clouds, rain, and storms of every kind, that it demands a brief consideration.

We have seen that in general, ascending air cools at the rate of 1° F. for every 183

feet. Consequently, so long as the rate of decrease of temperature with the height is equal to or *slower* than this, the atmosphere tends to remain in vertical equilibrium—that is to say, vertical motions will not arise spontaneously. The only interchange under such circumstances would be due to expansion and overflow, such as that described in Chap. IV., and which gives rise to the general circulation between the equator and the poles described in Chap. V. When, however, the atmosphere near the surface is not only heated by radiation of the changed solar rays by the earth, but is surcharged with vapour, it cools even at 62° F., our summer temperature in England, only 1° F. in every 400 feet of ascent, while at 92° F., as often occurs within the tropics, it cools only 1° F. in 500 feet. An upward movement once started, therefore, is able to continue, since the air is always warmer, and therefore lighter than that which it reaches above. Similar downward motions of the cool air above take place until a large proportion of the heat received near the surface is carried up aloft. The process is precisely analogous to that by which the hot water from the kitchen boiler is conveyed through the pipes to the cisterns at the top of a house.

These upward convection currents carry the life-giving heat to the cold regions above us, just as the arterial blood conveys warmth to our extremities, and are quite as necessary to the life of the atmosphere as the circulation of blood heat is to that of the animal. Were it not for this safe conveyance, moreover, of the surplus

heat away from our midst, there would often be a dangerous accumulation which would render life more insupportable than it is, especially in the tropics. When the existing rate of decrease becomes anything like 1° F. in 100 feet, or greater, rapid convection sets in, even if the air is comparatively dry, and clouds are formed with rain, and often lightning. If the air over a large district is affected, as sometimes occurs in the tropics, a cyclone is formed by the inrush of surrounding air, or, if the action is very intense and quite local, a tornado or whirlwind may result. This may be termed convection run riot.

Prof. Abbé, of the U.S. Weather Bureau, considers the limit of convection currents to be about 30,000 feet, or about the height of Mount Everest. Above this the temperature diminishes very rapidly, as indeed we find from the observations recorded on the free balloons, *L'Aerophile* in France and the *Cirrus* in Germany, which on March 21st, 1892, and July 7th, 1894, reached the same height of 10 miles. In the case of the French balloon, the temperature descended to 104° F. below zero, and at the same rate the cold of space—viz., minus 461°, would be reached at a height of about 30 miles.

The ordinary rate of decrease is in general about 1° in 320 feet after we rise above the first 100 feet.

From what has been said about the slower rate at which air saturated with vapour cools by ascent when the temperature is high near the surface than when it is low, we can readily understand why cumulus clouds and rain showers

occur in the daytime and in warm latitudes more readily than at night and near the poles. In fact, since at freezing-point and at sea-level even saturated air would cool as rapidly as 1° F. in every 277 feet, if it were not for imported convection systems and clouds there would be very little ascent and precipitation of condensed vapour at all in the arctic zones.

CHAPTER VII.

THE DEW, FOG, AND CLOUDS OF THE ATMOSPHERE.

WHEN we gaze skywards and see the filmy wisps of high-cirrus cloud, touching as it were, the very vault of heaven, or when we notice the ragged scud of the approaching storm, half covering the low hills, we are witnessing one of the first stages by which the water of our atmosphere becomes visibly separated from its gaseous companions.

Another stage is manifested when the pearly drops of dew gather on the blushing petals of our roses, or the rain drops from the frowning storm clouds. Still another transformation scene, and the beautiful six-rayed flakes of snow fall like flowers, scattered by an angel hand, and cover up the gloomy earth with a mantle of dazzling white.

Yet one more strange scene, and from the fiery thunder-cloud white balls of ice rattle down as though from some aerial glacier.

The chameleon character of this same water element is indeed a most fortunate circumstance.

Imagine what a dull world it would be without our gaudy sunset cloud tints. What a desert if it never rained.

It happens, however, that, unlike the other gases, water-vapour can undergo all its changes within the gamut of the temperatures we experience on this planet.

Solid at 32° F., liquid thence to 212° F., after which it becomes gas.

Moreover, the air is thirsty as it were, and so, from the liquid water, at all temperatures, and even the solid ice, vapour is ever ascending by evaporation and rendered invisible as it passes through the other gases.

There is a limit, however, to the capacity of air for such a temperance beverage, which, like the thirst of men, depends on the temperature. Thus, while a cubic foot of air at zero F. can hold but ½ a grain of vapour, at 60° F. it can soak up 5½ grains. At 80° F. as much as 11 grains can remain invisible in the same space.

To give a larger example. Suppose a room, 20 feet square by 10 feet high at 60° F., to be supplied with vapour until it could hold no more, then the air in such a room would weigh 304 lbs., while the vapour, if it were condensed to water, would weigh but 3 lbs., and fill three pint measures.

When air can hold no more vapour it is said to be saturated, and since, when it is cooled, it is able to hold less and less water, it can, even when unsaturated, be made saturated by being cooled down to a point of temperature some few degrees below. This point is called its dew point, and

depends partly on how damp, partly on how warm, it was at first.

When very warm and moist, a very slight lowering of temperature produces condensation into cloud and finally rain. Hence clouds and rain will form easier in warm countries, though other conditions may make them more constant in cold countries.

What we ordinarily term the dampness of the air, is not simply a question of how much vapour is present, since warm air may hold more than cold air and yet feel drier.

It is determined by the nearness of the dew-point to the existing temperature, and this depends on both the amount of vapour present and the temperature of the air in which it is dissolved.

Ordinarily the dampness in England is about 60 per cent. of what could be, but in very wet weather it rises to 90 per cent.

Over the ocean it is generally high both in warm and cold latitudes, while in the interior of continents and deserts it is occasionally as low as 15 per cent. As we rise above the earth towards the level of the lower clouds the dampness increases, until, at the cloud level, we reach dew- or cloud-point, where the air is saturated.

Dew itself is the moisture deposited on the surface of bodies near the earth's surface, which have cooled down by radiation below the dew-point of the surrounding air.

Dr Wells, in 1783, was the first to offer this explanation, and thought the moisture came entirely from the air around. Of late, however,

Mr John Aitken, of Edinburgh, and others, have shown that a large part of the moisture comes from the ground and the plants on which it is deposited. They are, in fact, constantly perspiring like human beings. In the day-time this perspiration is evaporated by the warmth and carried off by the winds. Only in the cool and calm of the night and early morning does it become deposited in drops of water.

Hoar Frost is simply dew formed when the dew-point happens to be below the freezing point of water.

Fog, or mist, may be termed a cloud of vapour, formed near the ground or water.

Sometimes, like dew, it is occasioned by the earth parting with its heat so rapidly as to cool down a stratum of air, just above it, below its dew-point, as occurs in the quiet anti-cyclonic weather, as it is termed, occasionally experienced in these latitudes in winter. Such fogs are usually fairly dry. Sometimes it occurs with a wind, when it is wetter and warmer. In such cases it usually comes off the sea, and is due to a warm moist air from the sea passing over a cool ground surface.

Locally, mists usually form in low river valleys, where the air is nearly saturated with vapour, rising from the water or moist land.

It seems strange, but it is nevertheless true, that the pretty white valley mist of the country is a near relative of the ugly nauseous fogs of our large cities. London fog is simply Thames river valley mist, mixed with the smoke poured forth by innumerable chimneys, which is unable to be

carried off, owing to an absence of wind above. When we can consume our own smoke, London fog, as we know it, will disappear.

Fogs at sea occur most frequently in summer, and especially near cold currents, as off Newfoundland, where the warm moist air off the Gulf Stream passes over the cold Labrador current; in the Behring Sea, where the Japan current meets the Arctic ice; off Cape Horn, &c.

At San Francisco, the Pacific Ocean breeds a chilly fog, which rolls up the streets, and obliterates the sun, even in May, but it is fortunately white.

The clouds of heaven have ever been an object of wonder and admiration to the sons of men. Long before Aristophanes wrote his immortal comedy, "The Clouds," we have numerous references to the clouds in the ancient Scriptures. Job says: "He bindeth up the waters in his thick clouds." "For he maketh small the drops of water; they pour down rain according to the vapour thereof." "Also can any understand the spreadings of the clouds"; while in Ecclesiastes we have a wonderful insight into the whole scheme of water circulation in the verse which says, "All the rivers run into the sea, yet the sea is not full. Unto the place from whence the rivers come thither they return again."

The first person who seriously observed and described the clouds was Luke Howard, the Quaker, who was first attracted to the subject in 1783.

Howard roughly divided clouds into three primary forms—stratus, cumulus, and cirrus—

and the same division also roughly applies to their height—low, intermediate, high.

Of late years, as our knowledge of their various forms and mode of origin has increased, this simple division has been found inadequate. The late Rev. Clement Ley, Mr Ralph Abercromby, Dr Hildebrandsson, Dr Vettin, and Messrs Ekholm and Hagstrom have observed their forms, behaviour, and heights, and developed quite a science of clouds.

The outcome of their researches is briefly summarised in the International Cloud Atlas, which has just been published, as a result of the International Committee held at Upsala, Sweden, in 1894.

Without going into details, the following gives a general idea of the varieties and corresponding heights, beginning with those near the surface; the character of the cloud being indicated as *wet* or *dry* according to the weather by which it is usually accompanied:—

VARIETIES OF CLOUDS.

Height in feet.	Name.	Description.	Character.
1. Sea-level up to 3000	Stratus	Elevated fog, so-called	Dry & wet
2. 4500 to 6000	Cumulus	Rounded heap	Dry
3. 4500 to 24,000	Cumulo-nimbus	Tower-like clouds with round tops and flat bases	Wet
4. 6400	Strato-cumulus	Rolls of dark cloud	Dry

Height in feet.	Name.	Description.	Character.
5. 6400	Nimbus	Masses of dark formless cloud	Wet
6. 10,000 to 21,000	Cirro-cumulus	Fleecy cloud, mackerel sky	Dry
Average height.			
7. 27,000	Cirro-stratus	Fine whitish veil giving halos round sun and moon	Wet
8. 27,000	Cirrus	Isolated feathery white clouds	Dry

I have left out one or two purposely for simplicity's sake.

Pictures of 1, 2, 4, 6, 8 are given in figs. (23); frontispiece, (1) and (2), (3) and (25), respectively.

It used to be thought that clouds were simply produced by the mixture of cold and warm air. In 1788 Dr Hutton of Edinburgh propounded his celebrated law of mixtures, which briefly asserted that, when two masses of air at different temperatures mingled, the colder air caused the vapour in the warmer air to condense, owing to the lower temperature of the mixture not being able to support the same amount of vapour in solution.

Dr Von Bezold has recently (1890) investigated the question, and has shewn that when saturated warm air mixes with unsaturated cold air, more cloud will be found than when saturated cold air penetrates unsaturated warm air. These two

cases are successively illustrated by opening the door of a laundry on a cold day and the door to an ice-house on a hot day. In the former case fog is at once formed, but not in the latter.

On the whole, however, he finds the effect of mixture to be very small and ineffective. In the case of Nature it usually occurs when a layer of warm air overlies a layer of colder air

FIG. 25.—CIRRUS CLOUD (var Tracto Cirrus, 1889).
P Garnier, Boulogne Observatory.

The shallow stratus, cirro-cumulus, and cirro-stratus clouds are partly due to this action.

Where one current crosses another at a different speed it raises waves or billows in it, just as when wind passes over the sea. In such waves there will be cloud at the crests and clear spaces in the troughs.

Mackerel sky, or cirro-cumulus, and the long

rolls of strato cumulus which follow one another at the rear of a storm, with showers and clear intervals of several hundred feet, are examples on a small and large scale of such aerial billows.

The most frequent cause of clouds, however, is the cooling, due to expansion of air, which ascends either freely, or by being forced up a mountain-slope, or drawn up an aerial eddy.

When the existing rate of decrease of temperature with the height is greater than $1\frac{3}{8}$ degrees per 300 feet, air locally warmed will ascend, and cool at this rate until the dew-point is reached, when vapour will be condensed and cloud formed. After this the air, since it is now saturated, will cool at a much slower rate—viz., about $\frac{4}{5}°$ F. in 300 feet.

Ascent after cloud level is reached is easy, therefore, so long as sufficient moist air is supplied.

Clouds are often found hugging mountains when the surrounding plains are clear.

In popular language mountains are said to "attract clouds." This, of course, is literally incorrect. The clouds are due in this case chiefly to the lower air being forced up the mountain side, and cooled by expansion down to dew-point.

Clouds also occur in connection with cyclones or large storms, both in the tropics and high latitudes.

This is because the air in the centres of such movements is damp to start with, and is continually rising and flowing out over the surrounding drier air.

The approach of such a storm when miles away is frequently heralded by the appearance of

tangled masses of the lofty cirrus cloud, which appear to converge to a point below the horizon, as in fig. 26, and which represent the overflow of the ascending damp air from the centre of the storm. These clouds are called the "warning cirrus," because their appearance and motion (from the storm-centre, unlike the lower clouds which move towards it) indicate the position and

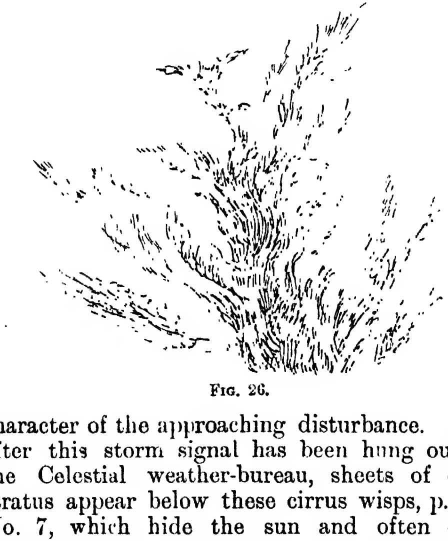


FIG. 26.

character of the approaching disturbance. Soon after this storm signal has been hung out by the Celestial weather-bureau, sheets of cirro-stratus appear below these cirrus wisps, p. 118, No. 7, which hide the sun and often cause a large halo, by refracting its rays through the prisms of ice of which they are composed. The final act in the aerial drama is ushered in by the appearance of high stratus and nimbus, No.

5, with ragged scud of stratus, No. 1, quite low down. These lower clouds move round and in towards the storm-centre, and thus make a considerable angle with that of the cirrus flowing out from it.

If a storm-centre, for example, bears S.W., the cirrus will also bear S.W., the cirro stratus S., the low clouds S.E., and the surface wind E.S.E.

The storm culminates with the arrival of the nimbus, from which rain or snow falls, after which the clouds disappear in the reverse order of their arrival, except that, owing to the more rapid motion above, in the direction in which the storm is moving, the upper clouds are blown towards the front, and are less prevalent in the clearing up showery weather in the rear. Fig. (23) represents the upper sky as seen after a storm, from a height of 7000 feet, in the Alps. A sheet of lower cloud or fog is below the spectator.

Fig. (27), overleaf, shows the position of the clouds round a European cyclone. The continuous lines are the isobars, and the dotted lines isotherms.

Almost the entire cloud mass, it will be noticed, lies to the front of the central ring of low pressure.

Amongst special forms of clouds may be mentioned the table-cloth of Table Mountain at the Cape, and similar table-cloths on Mount Pilatus, the Rock of Gibraltar, Atlas, &c. These are all formed by the passage of a warm moist current over a cold mountain which condenses its moisture

while it is moving across the summit. When, however, it has passed beyond the mountain, the vapour cloud mixes with the warmer air around, and, the vapour becoming reabsorbed, the cloud gradually tails off into invisibility.

In New Zealand, when a wet north-wester is blowing against the Southern Alps, and heavy

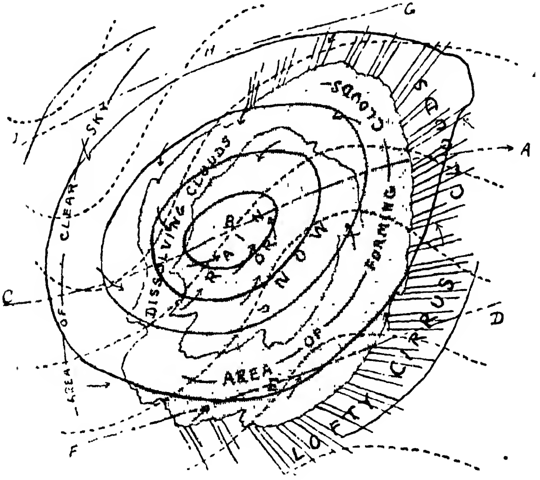


FIG 27.

rain is falling on their western sides, a long bar of cloud, due to similar causes, may be observed stretching along their summit ridge, extending some little distance from it above the eastern plains.

The eastern edge of this cloud roll remains fixed, though the wind may be blowing through it, as it often is in these cases, with hurricane violence.

Cumulus clouds indicate upward convection movements, and are more frequent in summer and warm countries.

They are frequently as tall and thick as they are broad, and often pierce up right into the cirrus.

Clouds of the stratus form, on the other hand, are usually very shallow compared with their area, which may extend for hundreds of miles. They indicate horizontal motions, and prevail mostly in winter and cold latitudes.

Clouds generally increase during the day-time, and reach their greatest height in the afternoon and evening.

The average rate at which clouds move increases with their altitude.

Cirrus clouds have occasionally been observed to move as fast as 250 miles per hour; but their average pace is more nearly 80 miles in America and 40 in Europe.

The average velocities for the different cloud levels observed at Blue Hill, near Boston, have already been given on p. 98.

The average heights of the clouds are greatest in summer and least in winter. Their average speed is least in the former and greatest in the latter season.

In fig. (25) a cirrus cloud is shewn, in which the delicate fibrous nature of this cloud

is plainly seen. The contrast between this ice crystal cloud, like a puff of white tobacco smoke, and the cumulus in the frontispiece, composed of heavy water drops, is very striking.

The Festooned cumulus in fig. (28) is a special form of cloud associated with thunder and hail-storms. It is a kind of inverted cumulus, in which a cold, very moist air is moving over a

FIG 28.—FESTOONED CUMULUS.
Sydney N.S. Wales. Jan. 18, 1893.

hot and very dry air such as frequently occurs in Colorado, Australia, and India. Under these circumstances all the condensation occurs in the cold layer, and none in the lower, hot one. Portions of the upper layer drop down in large bulbous masses like water balloons, which burst like soap bubbles and drop their moisture like

water running out of a cask. Sometimes this water never reaches the ground, being re-evaporated while passing through the hot air.

CHAPTER VIII.

THE RAIN, SNOW, AND HAIL OF THE ATMOSPHERE.

RAIN is the final stage of condensation of vapour back into water, of which cloud is a half-way stage. The mist which composes a cloud is formed of tiny drops of water about $\frac{1}{3000}$-inch in diameter. It used to be a puzzle to explain how these water particles were sustained, and it was at one time supposed that cloud particles were hollow. We know now that this is neither necessary nor true, since very small particles even of gold will remain suspended for a long time in air; the finer the particles the longer they take to fall. A slight upward motion of the air is therefore enough to keep them balanced. As condensation proceeds these particles grow larger by fresh coatings of water, and the larger ones fall down against the smaller and mingle with them until large drops from $\frac{1}{20}$ to $\frac{1}{10}$ inch thick form, which are no longer capable of being suspended and fall to the earth. Snow forms when the temperature at which this further stage of condensation occurs is below freezing point. Every snow crystal is a variety of a six-rayed

cluster, and is similar to the crystals of salts which are precipitated from a chemical solution. No one has watched the formation of snow, but it must be very similar to that of crystallisation out of a solution which is saturated with a chemical salt.

Hail, unlike the delicate snow crystals, is frozen water-drops. Its frequent association with thunder-storms led to the belief that it was caused in some way by electricity. This is, however, found to be untenable in the search-light of modern science, which shews that electricity is mostly an *effect*, not a *cause* of such mechanical disturbances. It is believed, that in such storms the rain-drops formed in one part of a storm are carried upwards by powerful ascending currents (twenty-five miles an hour is enough to sustain large drops) into higher regions of the atmosphere where they are solidified by the excessive cold, and being carried over with the overflow which takes place near the top, fall down until they are redrawn into the interior of the storm and again whirled up aloft. Receiving alternate meltings and freezings, and growing larger with each circuit they make in the atmospheric churn, they are finally thrown out on either side of the storm centre. This explains the fact that in a travelling hailstorm there are two bands where hail falls on either side, while, under the centre, it is often found that only rain has fallen.

Hailstones have often fallen of enormous sizes. In 1697, Robert Taylor found hailstones in Hertfordshire 14 inches in circumference.

In India, the writer remembers a hailstorm on the great Brahmaputra river when the hailstones cut holes through the tarpaulin cover of the steamer, which were so large that each one had to be mended with a separate patch. Hailstorms

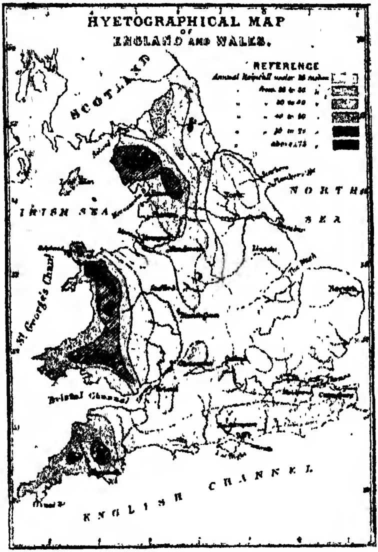


FIG. 29.

are intimately connected with tornadoes, and, like these phenomena, are more frequent over flat plains and in very hot and moist summers and countries.

The destruction dealt by hail on standing crops, vineyards, and orchards has led to means

being proposed for its prevention. Under the old idea of its connection with electricity, lightning rods were erected, but without avail. With ironical waywardness it fell in several instances on the rod-protected lands and avoided the others.

Planting of trees would be more effective, since this would tend to check the rapid heating up of the lowest stratum of air which is one of the chief causes of tornado and hailstorm action.

The general distribution of rain in belts over different areas of the earth's surface has already been alluded to.

Rainfall, like clouds, is more prevalent in mountainous than over flat countries, and for similar reasons, especially cooling by forced ascent of air.

In the accompanying mean annual rainfall maps of England and India, this will be readily seen. In England the heaviest falls will be observed to occur in the mountains of Cumberland and Wales, and generally along the hilly country of the West and North. In Scotland and Ireland it is the same. The lowest rainfalls under 20 inches all occur on the eastern sides of the country. This difference is partly due to the fact that the prevailing and most rainy winds are south-west and drop a good deal of their moisture before reaching the eastern parts, but even were these barriers absent, the rainfall over the flatter country on the eastern sides would not be very much increased. In India, in like manner the dark shading along the Western Ghats down the Bombay coast and along the Himalaya shews the influence of the mountains, the heaviest fall oc-

curring near the north-east corner of the Bay of Bengal in the Khasià hills, which offer an abrupt wall 4000 feet high up which the southerly monsoon winds, see fig (20), are forced.

Chirapunji, at the edge of these hills, has the largest rainfall in the world (about 500 inches),

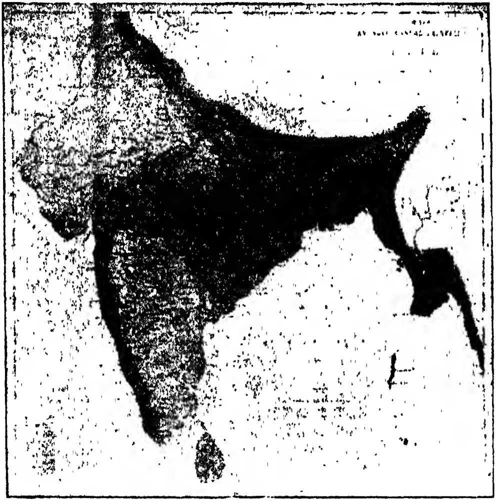


FIG. 30.

half of which falls in June and July. On the western side of the Ghats rain falls heavily up to 250 inches at Mahableshwar on their summits, while the tableland of the Deccan on their eastern lee side has a scanty supply and is one of the areas liable to drought.

The greatest amount of rain in a vertical

direction occurs at altitudes where the lowest cloud is thickest, that is, at about 3000 feet in Europe and 4000 feet in India above sea-level. In the interior of large continents where mountain ranges are absent, especially when they lie like Australia in the zone of perpetual high pressure dividing the tropical from the polar

FIG. 31.

wind systems, the rainfall tails off to a very few inches as we go inland.

The accompanying rain map of Australia shews this very plainly.

Over the whole of the lightly shaded area of central and west Australia there are less than 10 inches per annum.

This district can never support a large population.

CHAPTER IX.

THE CYCLONES OF THE ATMOSPHERE.

Every large storm of the atmosphere is now called a cyclone, because it is found that the air moves round and in towards a central area.

Formerly the word cyclone was only applied to the rare but violent storms of the tropics, while the words hurricane and tornado are still popularly used to signify small and large storms, indifferently.

The term tornado is now applied by meteorologists entirely to certain storms of quite a special class, differing from cyclones both in size, mode of origin, and effects, and it is to be hoped that the newspapers will learn eventually to give up a habit which only leads to confusion.

A cyclone is a large disc of nearly horizontally moving air circulating spirally round a central area over which the barometric pressure varies from one-fifth to as much as three inches below that at its border.

The direction in which the wind circulates is the same as that in which the earth's surface would appear to rotate in each hemisphere, if we stood several miles directly above the pole and looked downwards.

Cyclonic storms range in diameter from 20 to as much as 3000 miles.

A tornado, on the other hand, consists of a narrow column of air varying in width from 20 feet to 1400 feet which is rotating with immense velocity (up to 500 miles an hour) round a

central shaft up which it is also ascending with a speed in some cases amounting to 100 miles an hour.

A cyclone is an elephant, while a tornado is a scorpion, and they differ just as much in other respects as these two animals.

Tornadoes will therefore be specially referred to in the next chapter, together with whirlwinds, waterspouts, and thunderstorms, which belong to the same family.

Many poetic and graphic descriptions of the awful grandeur of a real tropical cyclone have been given. All descriptions, however, pale before the real thing.

The writer once experienced in Eastern Bengal the full violence of perhaps the most disastrous cyclone in regard to destruction of human life on record—viz., what is known as the Backergunge cyclone of November 1st, 1876.*

After several days of unusually quiet, muggy warmth and murky skies, lurid sunsets, and a general sense of impending doom, the rain began to fall in torrents and the wind to rise as the night came on, until at last I had to pile up the furniture against the windows to prevent their being burst inwards. The lightning flashed unceasingly, the thunder crashed, the wind tore past like a raging fiend. All the elements seemed to have broken loose, and one could almost fancy that the sober laws of physics were having "a night out." The very rarity of such

* June 12th of this same year witnessed the heaviest fall of rain ever measured in the world—viz., 40 inches in 24 hours, at Chirapunji, Assam.

hurricane violence made it all the more alarming. After a night of Tartarean gloom, mingled with truly horrible noise, morning broke sadly through gaps in the rampart of furniture, and I awoke to a knowledge that the plaster coating of my house lay strewn all over the compound. Later on I learnt to be thankful nothing worse had occurred, when I heard the awful news that 100,000 natives in the adjoining province had been drowned by the storm wave which was forced up the Bay on to the low-lying islands of Dakhin Shabaspore and Noakolly at the mouth of the giant Brahmaputra.

While cyclones are comparatively rare in the tropics, they are very prevalent, though fortunately as a rule in a milder form in higher latitudes. North and south of latitude 35° continual streams of small cyclones travel along the borders of the large permanent areas of low pressure or polar cyclones which surround either pole.

Sometimes one of these streams passes over us, in which case we experience wet and stormy weather. Sometimes they take a more northerly or southerly track.

Their place is frequently occupied by large areas of high pressure from which the air flows quietly outwards to feed the cyclones. These areas are termed anti-cyclones. Modern observations shew that the air which flows in towards and up the centres of the cyclone hollows flows out above and pours down the centres of these anti-cyclone heaps. While the weather in the cyclones, owing to the ascending damp air, is cloudy and rainy, the weather in the anti-cyclones,

where it is descending, is dry and clear. Years ago, until about 1830, there was little known about the course of the winds in cyclones, and ships which mostly experienced their full fury were at their mercy or the individual caprice of their commanders.

About the beginning of the century, Capper, of the East India Company's Service, announced that the storms of the Bay of Bengal were vast whirlwinds.

In 1828 Professor Dové of Berlin, and soon after Redfield of America, Reid of England, and Piddington of Bengal, developed, though with much diversity of opinion, the memorable "Law of Storms."

The chief point of this law was the fact that the wind always circulated round the area of lowest barometer in a nearly circular spiral (there was much unnecessary dispute on this point) against watch hands in the northern hemisphere.

They also ascertained that tropical cyclones originated in a belt about 10° on either side of the equator and travelled thence polewards along parabolic paths, occasionally crossing the tropical belts of high pressure, where they were broken on their western sides and into the north and south temperate zones.

The accompanying fig. (32) shows their general course under these circumstances.

An immediate consequence of these rough rules was to enable the mariner to avoid what was termed the "dangerous semicircle" (*i.e.*, the front half in the direction of travel), and to tell the direction of the storm-centre by noting the

direction of the wind. A rule by which this is simply remembered was afterwards enunciated by Dr Buys Ballot, the eminent Dutch meteorologist, thus :

"Stand with your hands stretched out on either side and your back to the wind, then in the northern hemisphere the centre of the cyclone

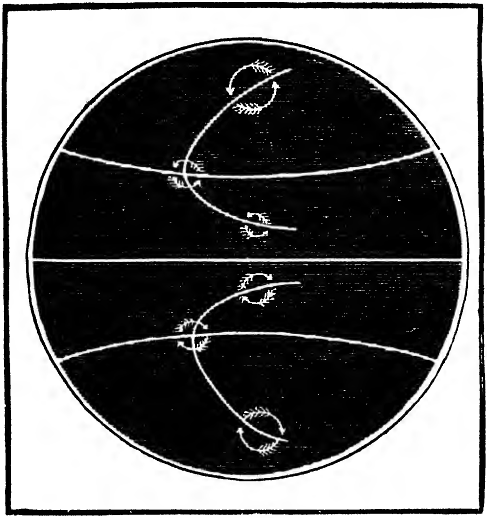


Fig. 32.

will be to your left hand." In the Southern hemisphere substitute "right" for "left."

Stated in this form the incurvature of the wind or its inclination to the isobars which contour round the central area is completely overlooked.

This inclination is found to increase with the distance from the centre, and the distance of the storm from the equator, quite apart from the fact that on land it is always greater than at sea.

Thus in the Philippine Islands (latitude 14°) it was found to be 62°, in the Bay of Bengal (latitude 20°) to be 57°, in the United States 40°, over the Atlantic 30°, and in England the late Rev. Clement Ley found it to be about 20°, while Captain Toynbee found it to be as much as 30° for the Atlantic in latitude 50° N.

Near the equator, therefore, it would be manifestly unsafe for a mariner to trust to the famous old "circular theory," which made the winds blow directly along the isobars, since there the centre of the storm, instead of being *directly* to his left if he stood until the wind blew directly upon his back, would actually be nearly in front of him.

Dr Meldrum of Mauritius, who was one of the most indefatigable reformers of the old circular law, mentions a case where as recently as January 24, 1883, the captain of the ship *Caledonien* deliberately ran his ship straight into the centre of a storm by following the old rule. The modern rules now advise the mariner (1) to avoid running before the wind, (2) to lie to on the starboard tack in the northern hemisphere or the port tack in the southern. By this means the vessel may be safely guided out of the dangerous vortex.

Tropical cyclones occur most frequently on the western sides of the N. Atlantic, the N. and S. Pacific oceans, and the S. Indian Ocean, also in the

Bay of Bengal and the China Sea, where they are termed Taifuns. The months in which they occur, September and October in the N. hemisphere, and February and March in the Southern, are soon after the periods when the equatorial calms or doldrums which lag behind the sun have reached their extreme northerly and southerly positions.

The air is calm and full of moisture, and this, combined with the fact that they are preceded and accompanied by torrential rain, has led to the conclusion that they are due to the upward convection of damp air which causes an indraft towards some central area. The heavy clouds and thunder and lightning which accompany them, fully bear out the same view.

Moreover, the energy supplied by the condensation of the vapour which allows the air to recoup itself for the loss due to expansion has been calculated to be sufficient to account for the immense wind energies they exhibit. Professor Reye of America calculated that the Cuban cyclone of October 5, 1844, used up in three days 473 million horse-power. Indeed, when we consider that the air in a cyclone 100 miles in diameter and a mile high weighs as much as half a million ocean steamers of 6000 tons a-piece, we can hardly wonder at the enormous amount of energy required to keep this in motion, at, say, 40 miles an hour.

On reaching land, tropical cyclones frequently break up. They are nearly unknown on the equator itself.

Ferrel again proved to be the Newton, who was able to weave all the disconnected facts relating to cyclones into a reasonable theory of cause

and effect. Assuming an inflow towards, and an upflow over, a given area, he was able to shew that at some little distance from the equator the spiral rotation of the winds and all the other phenomena of a cyclone would follow from the law of inertia on a rotating sphere explained in Chap. V. In an ideal case, where friction was unconsidered, the air would tend to rotate round a central area, as in fig. (33). At the centre the pressure would be very low, gradually rising to a maximum on the line separating the interior from the exterior gyrations. Outside this line the gyrations would be reversed. The interior region would be the true cyclone and the exterior a kind of anti-cyclone, usually termed a peri-cyclone. Where, as in nature, the air experiences friction, the pressure near the centre would be moderately low, the interior arrows would point inward towards the centre, and the exterior arrows outwards. The vertical circulation of the interior zone is simply shewn in fig. (34).

FIG. 33.

All the results from theory agree with those

observed. For example, an increase of the violence of the wind until it suddenly drops near the centre, where in tropical storms the clouds also disappear and the air becomes clear

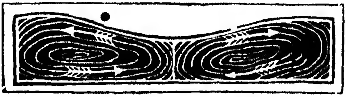


FIG. 34.

and calm for a space of occasionally 20 miles. This is called the eye of the storm, and the course of the air is believed to be that in the accompanying diagram, fig. (35), where the violent rotation produces such a centrifugal force as to cause some of the upper air to descend to fill the vacuum. Though the air is calm, the sea is here of that confused character most apt to make a vessel founder.

The weather of the tropical regions is controlled almost entirely by the regular daily and seasonal changes produced by the path of the sun in the sky between sunrise and sunset, together with that in its average altitude be-

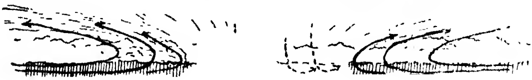


FIG. 35.

tween summer and winter, and is scarcely affected except temporarily by the rare passage of a cyclone.

In the extra tropics, that is to say from about latitude 35° to the Pole, the weather on the contrary is almost entirely made up of a succession of cyclones and anti-cyclones. The changes

introduced by these, completely dominate those brought about by the daily and seasonal causes.

Extra-tropical cyclones are moreover believed to be due to different causes to those of the tropics. Unlike the latter, they are most frequent in winter when the lower air is in a stable condition, and they sometimes occur without rain. They are supposed by modern specialists to be for the most part eddies in the large upper return currents, as they flow over from the Equator, and crowd into the narrowing space towards the poles. The effects at the earth's surface are the same as though the air rose spontaneously, since an eddy in mid-air causes the lower air to ascend just as a whirlpool sucks down water that is drawn into its vortex. The air which is thus forced to rise, forms clouds and usually rain, but the storm generally in such cases belongs more to the upper regions of the atmosphere, and is less violent near the earth.

The movement of cyclones is quite different from that of the winds that blow round their centres. The latter may vary from a gentle breeze to a hurricane of 100 miles, and the centre may remain stationary, but usually the cyclone itself moves over the earth at a speed which varies in different localities and for each disturbance.

We have already noticed the general movement of cyclones in fig. (32). In all cases when once they are formed they appear to be guided chiefly by the upper currents. In the tropics the west and poleward motion results from a combination of the lower westward moving trades and

the upper poleward moving return (or anti-trade) currents from the equator, but they often move here as elsewhere in very different paths, though generally north or south-westward.

Beyond the tropics they are driven eastward by the prevalent west to east winds, both above and below, and like eddies on a river are carried along by the stream.

They also exhibit a tendency to move round the anti-cyclone heaps which are here chiefly forced down-flows (just as the cyclones are here chiefly forced-up flows) so as to keep the anti-cyclones on their right in the northern hemisphere. This principle is made use of in forecasting their probable motions. There appears to be little known about the movements of detached anti-cyclones or areas of fine weather, but they frequently show a tendency to move from E. to W. as well as from N.W. to S.E.

The average speed of cyclones in different parts of the world has been determined by the late Professor Loomis from a very large number of cases, thus :—

Average Speed of Cyclones over the Earth.

United States, .	28 miles per hour.
North Atlantic,	18 ,,
Europe, . .	16 ,,
West Indies, .	14 ,,
Bay of Bengal and China Sea, .	8 ,,

The greatest amount of cloud and rain and the highest temperature occurs in their front halves, and their vitality, especially in the

tropics, appears to depend on the continuance of condensation and rainfall, which allows the air to flow readily up their centres.

The vitality and longevity of some of these storms is wonderful. Thus a few years ago Mr H. Harries, of the English weather bureau, traced a storm which started in the Japan seas right across the Pacific, America, the Atlantic, and Europe, until it was lost sight of in the Baltic.

The forecasting of daily weather in high latitudes requires a knowledge of the birth and subsequent movements of particular storms. In the tropics, where the daily weather changes are small, the most important problem is the prevision of average seasonal weather. This requires something more than a mere knowledge of travelling cyclones, and observes large waves of pressure which take months to travel from equator to pole, or from west to east. By this means, seasonal forecasting six months ahead is carried on in India, and a similar method could be applied to the average weather of other countries. The waves of pressure caused by the passage of cyclonic storms compared with these large waves are like the ripples on an ocean billow.

The passage of cyclones and anti-cyclones introduce special winds which possess peculiar characteristics, due to origin and direction. The sirocco, of Italy and Greece, the leveche and solano of Spain, the leste of Madeira, the Khamsin of Egypt, the Kona of Hawaii, and the brickfielder of Southern Australia are all examples of the wind in the front half of a cyclone which, coming from regions nearer the equator,

is invariably warm, and dry and exhilarating, or damp and muggy, according as they have travelled over sea or land.

The lassitude and irritability produced by the solano has given rise to the Spanish proverb, "Ask no favour during the Solano." The Italian sirocco induces similar weariness.

At the rear of the cyclones of the temperate zone which travel from W. to E. in both hemispheres, the wind blows from some polar direction.

Locally are thus produced the cold "Nortes" of Mexico, the "blizzard" of the States, which is accompanied by blinding snow, the "Mistral" of the Rhone Valley and the Gulf of Lyons, the "pampero" of Mexico, and the "southerly bursters" of Australia.

The "bora" of the Adriatic is of the same species, but possesses a peculiar, penetrating cold by being drawn down towards the cyclonic depression from a lofty plateau where it has acquired great cold by radiation.

A peculiar wind arises in connection with the motion of cyclones over mountain ranges, called in Switzerland the "*foehn*" and in America the "*chinook*." In New Zealand it is locally known as a "hot north-wester," and it is found to occur everywhere on the lee side of mountain ranges running athwart the paths in which the cyclones travel. This wind is uncommonly hot and dry, and melts the snow on the Alps in one night more than the sun shining for several weeks.

In America the chinook blows on the eastern side of the Rockies and raises the temperature of a long belt of that part of the country per-

manently above what it would otherwise experience.

The way in which this heat is derived has been revealed by a knowledge of atmospheric physics, and is really quite simple when, as the professor of legerdemain is fond of saying, "you know how it's done."

On the windward side, the air after it has reached cloud level, loses only about $\frac{4}{5}°$ every 300 feet it ascends. When it has reached the top of the range it has lost a great deal of moisture in the shape of rain, and as it descends on the lee side as dry air, it gains heat at the rate of $1\frac{3}{5}°$ per 300 feet, or, in other words, it gains an extra $\frac{4}{5}°$ for every 300 feet it descends. Consequently, by the time it reaches the lee valleys it appears as a hot, dry wind. The higher the mountain chain the hotter the wind. It used to be thought that the famous hot nor'-wester of the Canterbury Plains in New Zealand derived its heat from Australia, but it is found that when it is blowing hot and dry in Christchurch it is rainy and cool on the western side of the southern Alps.

CHAPTER X.

THE SOUNDS OF THE ATMOSPHERE.

As inhabitants of this earth planet we are far more dependent for our happiness on sound, even inharmonious noises, than we are inclined to admit. A world without the voices of men

and animals, without music and song, wrapped in profound silence would be insupportable. And of all phenomena, sound is one which peculiarly belongs to the atmosphere, since while light can travel wherever æther exists, even through vacuum, sound cannot exist apart from air. Every sudden movement of the air propagates a series of waves from the point of origin of the motion similar to what occurs in water when a boy throws a stone into a pond.

A sudden meeting of two solid objects gives a blow to the adjoining air which suffices to originate a series of such air waves. These waves differ from those on the surface of water in one essential point—viz., that whereas in water waves, the water moves up and down, while the wave motion is propagated horizontally; in the case of air waves, the air moves backwards and forwards in the same direction as that in which the wave is transmitted. The air is thus alternately compressed and dilated, and as such conditions travel forward in all directions from the origin of the disturbance, the sensation of sound which is produced when such waves meet the ear is propagated through considerable distances. When these waves enter the human ear they beat up against a delicate plate, or tympanum as it is termed, of hard skin, and cause it to shake backwards and forwards. The movements of the tympanum are passed on by a series of bones in loose contact, which filter out irregularities and pass the waves into a kind of aural piano fitted with a number of delicate filaments instead of keys, each of

which is attached to a separate nerve. Upon this piano tunes are played, as in the case of an ordinary piano, while from our brains we experience the sensation of high and low notes, harmonies and discords, just as similar effects can be produced on the artificial instrument. We can only distinguish such waves as sound, when they follow one another more rapidly than 16 times per second, or less rapidly than 38,000. Waves exist beyond these limits, but to us they are inaudible. A deep bass voice causes about 100, and the highest soprano has reached about 2000 waves per second.

All sounds travel at about the same rate—1120 feet every second in air of ordinary temperature. Consequently when we hear thunder follow about five seconds after a flash of lightning, we know it is a mile distant.

The dense air near sea-level is a better medium for transmission of sound than the more rare air at great elevations. Sound rises upwards easier than it descends, and travels better through damp than dry air. In a balloon Mr Glaisher heard the noise of a railway train at four miles high when in the clouds. When clouds were far below him no sound was heard.

Echoes or reflections of sound are often a very curious atmospheric phenomenon. To echo the last word spoken distinctly, the reflecting surface must be at least 110 feet away. A full sentence requires a much greater distance. A dome-shaped roof often produces a multiple echo, the reflected waves undergoing continual reflections between

the floor and the roof, until the wave motion is finally converted into heat.

In the Taj Mahal, at Agra, the incomparable marble mausoleum, erected by Shah Jehan to the memory of his wife, the central dome gives a beautiful multiple echo.

In buildings of a paraboloid form, such as the Mormon tabernacle at Salt Lake City, Utah, the slightest sound, such as a pin dropped at one end of the building, can be heard near a certain point at the other end. Yet this building can seat 11,000 people: The Whispering Gallery at St Paul's is another example of the same kind. In the first case the sound waves are all reflected toward the same point, and therefore reinforce each other enough to render their continued effect audible. In the latter, their continued reflection between the walls of the gallery prevents the loss they would usually experience by spreading out in all directions.

Thunder can be heard at 30 miles, explosions at 100 miles or over. Thus the firing at Waterloo was heard at Dover. The sounds of volcanic eruptions, however, have been heard at immense distances. In 1883 the eruption of Krakatoa, a volcanic island in the Sunda Straits, was heard over an area equal to one-thirteenth of the entire globe. In one direction the sounds were heard at Rodriguez in the Indian Ocean, 3000 miles away (they took four hours to reach it), and in another, at Alice Springs, in the very centre of Australia. At intermediate points every place thought a vessel was firing distress guns, and search was made for the supposed vessel over an

area as large as Europe. Besides sounds, large air waves were propagated, which expanded in circles until they girdled the earth and then converged upon the Antipodes of Krakatoa, whence they were reflected back again to Krakatoa, and so on no less than seven times. Every recording barometer in the world shews little notches in its record for August 27 and following days. Each notch shews the passage of the wave backwards and forwards from Krakatoa. These waves travelled with the same velocity as the sound waves, and took thirty-six hours to perform each circuit of the globe.

CHAPTER XI.

THE COLOURS AND OPTICAL PHENOMENA OF THE ATMOSPHERE.

THE story of our advance in the knowledge of Light, like that in most other branches of physical knowledge, is one of gradual dispersal of error and perplexity, and the dawning of truth and harmony.

Even the great Newton's emission theory, by which light was supposed to be due to a kind of bombardment of minute corpuscles, broke down when subjected to the keen analysis of modern science, and another generation, led by Huyghens, Euler, Young, and Fresnel, was required to formulate and develop the modern theory of wave motion of the invisible aether which surrounds

and penetrates all matter. This theory of aether-wave motion accords with all the observed facts, and enables discovery to march forwards with certainty and power.

Light and heat are simply effects of the same wave motion. When the waves of aether are between $\frac{1}{67000}$th and $\frac{1}{28000}$th of an inch in length, they produce the effect of light upon our eyes, and at the same time heat upon our faces.

When the rays of other lengths between these extreme limits reach us, they appear of certain colours corresponding to their wave-length or position in the so-called spectrum which is produced when white light is passed through a glass prism. The longest waves produce red light, and the shortest blue or violet, the order of colours corresponding to decreasing wave length, and therefore greater rapidity of wave succession, being red, orange, yellow, green, blue, violet. White light is made up of all these rays mixed. When these rays either singly or mixed, as generally happens, come in contact with air, or matter floating in it, they set up small oscillatory motions in the tiny molecules of which it is composed. The effect of these motions constitutes a condition which we term heat or light, according as it affects certain nerves. A portion of the radiant energy is used up in this generous performance, or in other words is said to be absorbed. Relatively, more heat can be derived from the long wave rays of red colour, and more light from the short wave rays of violet colour, but both are produced all through the spectrum. Heat and light, therefore, are simply effects of

the same wave motion according as it specially affects our senses of sight or feeling, and they both inseparably belong to the same radiant energy of wave motion of the ether, started by a body already in a state of incandescence like our sun. Rays near the violet end of the spectrum produce the chemical action noticed in photography besides being converted into heat and light. *Dawn* and *twilight* have ever formed expansive themes to the poet. "Rosy-fingered dawn" is a familiar metaphor of the immortal Homer. These half lights are the result of reflection of the sun's rays when below the horizon, chiefly by the small dust and water particles at great heights in the atmosphere. The fingered appearance alluded to by Homer is due to the light passing between clouds or mountains below the horizon. The reddish colours of the clouds at both times are chiefly due to the selective scattering which is exerted by the dust and vapour suspended in the air. The smaller waves corresponding to the blue rays, as we have already remarked in Chap. VI., are more easily turned aside than the larger ones corresponding to the red rays, and this dispersion reaches its greatest effect when the sun is shining through a great thickness of air at its rising and setting. Consequently red rays predominate at these times and tint the clouds as they successively receive its parting or coming rays. Occasionally when a sunset has disappeared below the western horizon it is brilliant enough to cause a second sunset on clouds near the western horizon by reflection, just as though it were the sun itself.

When the dust ejected by the volcano of Krakatoa Island in 1883 had spread in a layer above 50,000 feet all over the world we had such brilliant primary and reflected sunsets, which often lasted $1\frac{1}{2}$ hours after the sun had disappeared.

The reflection was assisted by a peculiar action called diffraction, by which white light meeting fine dust is split up into its coloured elements, just as though it passed through a glass prism.

In this way a huge coloured ring called a *corona* was produced round the sun. This ring is blue inside, and exhibits thence all the spectral colours in turn, ending with red at its border.

Inside this ring a white central glow was produced even when the sun was high up in the sky. When it was setting this diffraction glow became pink and finally red through the extinction of all other colours except the reds owing to the great length of air traversed by the rays. Such glows are always present to some extent, due to diffraction by suspended water particles, but when the Krakatoa dust was still in the upper atmosphere they were intensified, and the ordinary reflections prolonged far beyond their usual limits.

Similar small coronæ are produced when small clouds pass over the sun and moon. On a small scale they can be frequently observed when we look through our eyelashes at the flame of a candle or gas lamp.

The smaller the particles of cloud the larger the corona. Hence the large corona seen round the sun after Krakatoa, called Bishop's ring from its discoverer in Honolulu, showed that the material was composed of very small particles.

A *halo* is a large ring seen when the sun and moon shine through a thin sheet of cirrus or cirro-stratus, and can only be produced by refraction through ice-prisms. Consequently its presence is one indication of the ascent of vapour into very lofty regions, such as occurs in cyclones. It is thus a signal of the approach of rainy and stormy weather.

A primary halo is always the same size—45° diameter. Sometimes, however, secondary halos are formed by more complicated refractions and reflections of light through the ice prisms.

For example, outside the ordinary halo, and concentric with it, an *extraordinary halo* is occasionally seen of 90° diameter. Intersecting these halos, a huge circle passing through the sun and parallel to the horizon makes its appearance. At the points of intersection of these halos, the light is so reinforced that the patches look like separate suns, and form what are termed mock-suns or parhelia. Similar appearances round the moon or mock-moons are termed paraselenæ. At the opposite points of the sky similar mock-suns are occasionally formed. Some years back the author saw four mock-suns at the same time. Two in front where the primary halo intersected the large horizontal halo, 22½° on each side of the sun, and two behind him, making angles of 157½° with the sun on each side.

The *mirage*, or serab (illusion), as the Arabs term it, is a phenomena which has often formed a subject for the poet as well as the artist.

The thirsty traveller in the dreary and parching wastes of the Sahara and Arabian deserts

frequently sees looming up in the distance a beautiful lake dotted over apparently with islands and trees. This lake is an illusion produced by the bending or reflection of the light that occurs at the boundary of two strata of air of different temperatures. In this case a layer of cool air overlies one of very hot air just above the heated sand. Any object, such as a tree or mound above this layer, has its image inverted by reflection, while the light from the ground is thrown back by what is termed internal reflection. Consequently the effect is just the same as though a layer of water were really present. A special kind of mirage is termed "looming." In this case objects which are ordinarily below the horizon are seen raised above it, sometimes inverted and sometimes erect. These effects are due to a great increase in the ordinary refraction which takes place near the horizon, due, probably, to a cold and dense layer of air over the sea, overlain by a warmer layer derived from the neighbouring land. The famous Fata Morgana or castles of the witch Morgana of Reggio are an instance of this kind of mirage. During certain conditions of the air the inhabitants of Reggio see castles and men and trees, etc., suspended above the sea in the direction of Messina, whose reflected image they really are. A southern imagination converts them into enchantments.

A curious effect of looming occurred once at Malta, where the top of Etna appeared by refraction like an island in the sea. Several ships sailed out to take possession of this supposed

new island, but soon the image vanished and the quest was seen to be vain.

This story was paralleled more recently when the gorgeous Krakatoa sunsets first made their appearance in America. A local fire brigade in a raw Western township, seeing the sky so red, with more zeal than wisdom harnessed up and set forth with all speed to put it out. When they ultimately found out their mistake they were not a little put out themselves.

In the polar regions, where the sea is usually colder than the air, the images of objects below the horizon are frequently reflected to the observer from the top warm layer and appear inverted. If the upper warm layer is of no great thickness, there is thus often both a direct and inverted image. Scoresby once recognised his father's ship, the *Fame*, by observing its inverted image through a telescope. The real ship was afterwards found to have been thirty-five miles distant.

The *rainbow* has always been a majestic symbol of the union between earth and heaven.

Iris, the goddess of the rainbow, was one of the most graceful of the Grecian deities. She was represented as the messenger between Olympus and his earthly subjects.

According to the Teutonic mythology the rainbow was the bridge over which the heroes passed to the festive abode of Walhalla.

Robbed of its fanciful mysticism, the rainbow loses nothing of its beauty when we know that it is the result of the refraction of the white light from the sun as it enters the rain-

drop subsequently reflected from the back of the drop to our eyes. The whole operation is so wonderful. The different coloured rays which make up the white ray when they meet the new surface, part company according to their wave frequency, and travelling along separate paths are reflected by the mirror back as though they were painted in the sky. The tiny violet waves being more bent inwards, appear inside the bow, while the longer red waves form the external boundary. Ordinarily the earth cuts off the lower half of the bow, and when the sun is more than 40° above the horizon, the entire phenomenon disappears.

Inside the bow the violet is occasionally seen repeated in what are termed supernumerary bows, while the external bow is often visible in which the colours are reversed. The explanation of these belongs rather to a book on optics. The "Spectre of the Brocken" is simply a shadow of the spectator projected on to a screen of vapour rising up from the surrounding valleys, and may be seen on any mountain where the conditions are favourable.

The "ignis fatuus," or wandering flame occasionally seen in marshy land, or over churchyards, where it is called the "corpse candle," is believed to be merely a distillation from the soil of phosphoretted hydrogen gas which has the property of self-ignition on emerging into the atmosphere.

The "aurora polaris" or "northern lights" are a manifestation of quiet electrical discharge round either pole, attaining its greatest brilliancy

and frequency near the magnetic poles, which are at some distance from the true geographic poles. In the northern hemisphere the belt of greatest frequency (80 auroras per annum) occurs from latitude 50° to 62° in America, and from latitude 66° to 75° over Siberia. From thence they diminish both north and south.

The Aurora exhibits various forms. Streamers, curtains, bands, and rays, and it frequently coruscates, whence the name "Merry Dancers." It is believed that the Aurora is a sheet of rays which converge downwards towards the magnetic axis of the earth, a kind of luminous collar, the top of whose arch is as much as 130 miles above the earth, though parts of it are believed to be quite near the earth. It is therefore an electrical discharge taking place in highly rarified air or vacuum. Lemstrom of Finland recently succeeded in causing an artificial aurora by suitably imitating what is believed to occur in Nature. The Aurora is certainly closely connected with the magnetic condition of the earth and also of the sun. When any great sun-spot appears on the latter orb, the magnetic balance of the earth is affected, as shewn by the irregular movements of the magnetic needles and the simultaneous appearance of auroræ at both poles.

CHAPTER XII.

WHIRLWINDS, WATERSPOUTS, TORNADOES, AND THUNDERSTORMS OF THE ATMOSPHERE.

BESIDES the large cyclones, there is a peculiar group of local disturbances or storms of the atmosphere which, according to their violence, occur in one or other of the above forms. The harmless dust-whirl we see arise on a still day in early summer, and sweep across the young corn, is but the embryo of the terrible tornado of the Middle United States.

The dreaded simoom of the Arabian Desert is simply a larger whirlwind laden with the dust of the desert. Where the whirl is broader and higher, and the air is moist, we have the common thunderstorm of Europe with or without hail, the "nor'-wester" of India, the "pampero" of the Argentine, and the so-called "arched squall" and "bull's eye squall" of the tropical seas

When the action is very intense and concentrated, we have the "tornado" which is common in the Mississippi Valley. The freaks of some of these tornadoes, while generally of the tragic order, occasionally border on the ridiculous. Thus—even in India where they occasionally occur in a mild form—it is stated that in the district of the Brahmaputra, on March 26, 1875, after a tornado had passed the village of Uladah a dead cow was found stuck in the branches of a tree some 30 feet from the ground.

In America, in the tornado of June 4, 1877,

at Mount Carmel, Illinois, the spire, vane, and gilded ball of the Methodist Church were carried fifteen miles to the north-eastward. In other cases ploughshares and even houses (generally of wood) have been carried up into the air, and, so to speak, transplanted. In the recent terrible visitation at St Louis, in June 1896, it was stated that a carriage was lifted from the road up into the air and gently let down again 100 yards off without damage, while at the end of this remarkable performance the coachman's hat was declared to have remained securely attached to his head. This last circumstance sounds a little tall, but there is no obvious exaggeration in that given by one spectator who informed the writer that he looked up a street in St Louis and saw everything—horses, carriages, people, and furniture being whisked along in tumultuous chaos towards him as the centre of the tornado passed over it.

When the centre of a tornado passes it seems to sweep everything movable along with it, often destroys the most substantial buildings and cuts a clear lane through a forest. In all these cases, the prime cause appears to be a local instability of the air due to an aggregation of heat near the surface, combined with an incursion of cold air in the stratum above. These together cause a rapid fall of temperature in a vertical direction.

In such a case even dry air may temporarily ascend in a narrow column and burst through the upper layers.

When once this has taken place the surround-

ing air rushes in to supply its place, and there ensues a whirling round just as in the case of water running down through a sink.

In Tornadoes the whirling round of the air is not due as in that of the large cyclones to the deflection caused by the rotation of the earth, since this would be practically insensible for movements within such limited areas. It is due to the rapid development of gyration as the air is forced inwards towards the centre when once such gyration has started. The slightest deviation to one side of the direct path to the centre is enough to start a gyration, and any slight irregularity in the flow suffices to cause a deviation.

After the whirling has once started, the gyrations near the centre become so rapid that ultimately a funnel shaped column of highly rarefied air is produced, which is marked by the appearance of a sheath of cloud or water within which, in extreme cases, is a nearly complete vacuum. Round and up the sides of this the air ascends, flows out above, and again quietly descends over a wider area.

When the air is dry, the action, as we know, cannot continue very long, since the uprising air soon reduces the vertical temperature differences below 1° in 180 feet. Dust whirls and sand storms are consequently short-lived and never of destructive violence.

When, however, the lower air is very damp as well as hot, the action can go on for a much longer time and with far greater energy.

Lieut. Finley of the U.S. Navy, who has made

a special study of American tornadoes, estimates that the velocity of the wind rotating near the centre of a tornado may reach as much as 500 miles an hour, and exert a pressure of 250 lbs. to the square foot. Even the upward velocity near the vortex probably amounts, in many cases, to over 100 miles an hour, otherwise it could not sustain the objects it visibly does.

The awful effects frequently produced by the arrival of such a piece of what may be termed *meteorological dynamite* can therefore be understood. The central column of rarefied air by reason of its expansion is cooled below dew point. Hence, whatever vapour exists there, becomes condensed into a visible sheath. This is the cause of what are termed *waterspouts*, which are only a mild form of tornado. In the real tornadoes, the black funnel shaped cloud, which forms one of their most marked features, is due to the same causes. The popular notion of a waterspout accounts for the water by imagining it to be drawn up from the sea. But this is erroneous. When waterspouts pass over the sea, they cause a disturbance and slight upward rise round their bases, but the long visible column, often half a mile in length, which dips down from the clouds, is entirely composed of vapour, condensed out of the inflowing air. As Ferrel puts it "the cloud (or rather the conditions which favour the production of cloud) is here drawn down towards the earth by the reduction of pressure produced by the rapid whirling of the air."

At the same time, the downward dip is only

an apparent and not a real descent of water. As long ago as 1753, indeed, the great Franklin correctly explained this where he says—

"The spout appears to drop or descend from the cloud though the materials of which it is composed are all the while ascending, *for the moisture is condensed faster in a right line downwards, than the vapours themselves can climb in a spiral line upwards.*"

The freshness of the water in a marine spout is clearly testified to in a story quoted by Prof. Davis in his Meteorology:

A water spout had fallen upon a vessel and poured its contents so freely over the captain, that he was nearly washed overboard. He was asked afterwards, rather jocularly, if he had tasted the water? "Taste it," said he, "I could not help tasting it. It ran into my mouth, nose, eyes and ears." Was it then salt or fresh asked his querist? "As fresh," said the captain, "as ever I tasted spring water in my life."

Waterspouts occur mostly in the tropics, and during the day hours. They are children of the sunshine.

The prevailing funnel shape, tapering downwards, of the waterspout or tornado cloud, is a consequence of the increased pressure of the air near the surface. Above the surface the absence of friction and the lower pressure allows the central area of rarefaction, produced by the rapidly whirling air, to extend for some space laterally. Lower down the centrifugal tendency of the rotating air is met by increased inward pressure and is thus confined to a narrower

space. Outside the central core the air moves gently towards the centre. When water in a basin is descending through a hole, a similar gentle flow may be observed, the rapid whirling only extending for a short distance immediately around the hole.

Even in destructive tornadoes the area of dangerous damage and violent wind is confined to comparatively narrow limits. The width of the destructive path of the tornadoes in America has been found by Finley to vary from 20 feet to about 2 miles, the average being about 1369 feet.

The length of their paths is usually not more than 20 miles, since the forces which give rise to them, unlike those of cyclones, depend entirely on specially marked vertical gradients of temperature which seldom prevail simultaneously over large areas.

The mode in which the air travels up into and round these phenomena, may be gathered from the adjoining Fig. (36). Instead of rising up vertically it travels along the lines which are represented as winding spirally round the funnel until it becomes cooled partly by ascent and partly by expansion into the tornado-core and its vapour becomes visible at a point *C* considerably below the ordinary cloud level *FH*.

Tornadoes may be regarded as a kind of atmospheric eruption analogous to those by which the volcanic energy of the earth's interior is expended in one spot.

They prevail where the local conditions favour the establishment of explosive heat conditions.

For example, where the geographical conditions are favourable to the facile movement of cold air from the north alongside or above warm air from the south.

Such an area exists *par excellence* over the flat river basins of the Mississippi, Missouri, and Ohio. The states lying in these basins are

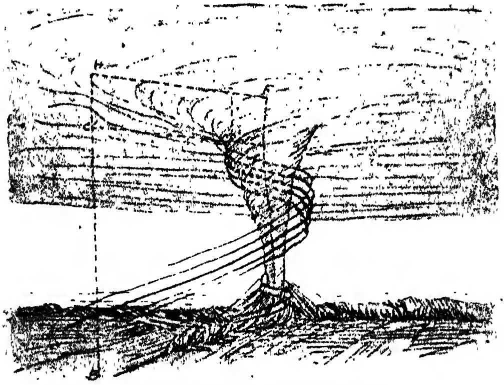


FIG 36.—TORNADO FUNNEL CLOUD.

those in which tornadoes are found to be most prevalent.

The general north and south trend of the mountains and hills in America favours the flow of air of such contrasted conditions, while the prevalent east and west ranges in the old world make them act as preventive barriers.

The time of year most favourable to the production of tornadoes is Spring or early Summer,

when the earth is heating up rapidly, and the air above it is still cold from the effects of the preceding winter. Lieut. Finley found May to be the month of greatest frequency of tornadoes, while during autumn and winter they are almost absent. The time of day at which they mostly occur is in the afternoon when the accumulation of heat in the lower layers has reached its greatest amount. When the gun is loaded it only requires the slightest pull on the trigger to release an immense potential of energy. Half a degree more temperature and the tornado is born and starts off on its wayward journey.

The destruction caused by these tornadoes in America is hardly realised in Europe which is so happily exempt from them. At the same time the deaths from this cause in the U.S. are estimated to be less than those caused by fire and flood.

Thunderstorms, like tornadoes, originate from the uprise of a mass of warm moist air, but the width of the column of uprising air is much greater, and the whole action is much less concentrated and violent.

The vertical anatomy of a thunderstorm is shewn in Fig. (37) where the spectator is supposed to be standing to the right and viewing an advancing storm. First of all he sees a layer of cirro-stratus cloud (*c*)* commonly in the western sky in the afternoon. Gradually this grows thicker, and from its under surface

* This layer should extend as far again as the width of the figure to the right. The exigencies of space have necessitated its curtailment in the adjoining figure.

festoons (*f*) similar to those in the "Festooned Cumulus," Fig. (28), appear.

The cirro-stratus may extend from 10 to 50 miles in advance of the storm. In this way as soon as they are visible, thunderstorms may readily be forecasted within a few hours by experts such as the late Rev. Clement Ley. Then follow the thunderheads (*t*) of cumulo-nimbus (as in frontispiece) which represent the front portion of the uprising current. Below these, a low level base (*b*) of similar cloud is seen, underneath which is a rain curtain (*r*).

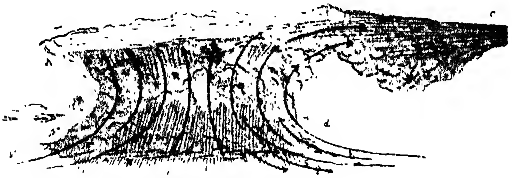


FIG. 37.—THUNDERSTORM IN SECTION.

A ragged squall cloud (*s*) rolls beneath the dark cloud mass, a little behind its forward edge, and the whole structure moves over the land at the rate of from 20 to 50 miles an hour. As the squall cloud comes overhead the wind changes suddenly from an in-flow to an out-flow, represented in the figure by two arrows near the surface, with heads to the right. In contrast with the hot muggy air preceding the storm, this squall is deliciously cool, especially in a Bengal north-wester. Simultaneously with the arrival of the squall, the barometer rises

about $\frac{1}{20}$th of an inch, the rain or hail begins to fall, the lightning flashes and the thunder crashes right overhead, until the centre passes, and everything gradually resumes its former aspect, except the temperature which has been permanently lowered. The outflowing squall is believed to be very similar to the recoil of a gun when it is discharged. The humid air in the centre of the storm expands so suddenly in rising, that it actually kicks against the surface air, and drives it outwards in the direction where the pressure is least, that is towards the front of the storm.

Thunderstorms travel along with the movement of the air near their tops, while the preceding inflow in front occurs as in the figure in the contrary direction. This has given rise to the saying that they travel against the wind.

There are at least two kinds of thunderstorms. One is chiefly confined to the equatorial regions and the summer in high latitudes, and the other occurs in connection with cyclones in their south-east quadrants.

They are both due to the convectional ascent of warm moist air, but in the former case it is locally manufactured during the daytime. In the latter, it is often imported from a distance. In the former storms, the cloud is isolated and continuous often from 1000 feet up to the cirrus level at 30,000 feet. When it ceases to ascend it spreads out in a sheet in all directions, so that a thunderstorm cloud of this kind often presents in the distance the appearance of a huge anvil.

The cyclonic thunderstorms are not so dependent on local sun heat, and frequently occur at night, and in the winter season in Scotland, Norway and Iceland. In this case the cooling of the upper air produces the same effect as the heating of the lower.

Like the tornadoes they travel mostly eastwards, and their occurrence generally betokens the existence of a cyclone centre to the N.W. in Europe, and to the S.W. in Australasia.

As long ago as 1752, Franklin proved by his memorable kite experiment at Philadelphia, the identity of lightning with electricity artificially produced on the earth. There is, however, still very little known as to the exact cause of the accumulation of electrical potential which finds vent in the lightning discharge.

The air is ordinarily found to be charged with a certain amount of positive electricity, while the earth is usually negative. The concentration observed in thunderstorms, is believed to be due to the increase in electrical quantity, and rapid increase in electric potential (or power of doing work) caused by the masses of damp air which rise up, form towering cumulus clouds, and discharge their vapour in drops, by condensation.

As the tiny droplets of vapour in the cloud unite to form single large water drops, the electrical charges which always exist to some degree on their surfaces, become added together. Not so the surfaces; since the surface of a single globe is always smaller than that of two globes which unite together to form it. Consequently, as more and more droplets unite together, the

electricity has less room over which to spread itself. It consequently increases in thickness, or in electrical language, density. It takes 300 trillions of droplets to form a single rain drop, and it thereupon results that the surface of the rain drop is one 8-millionth of the area made up of all the surfaces of its component droplets. Therefore the density of electricity on the resulting raindrop is 8 million times increased and by a simple electrical law its potential or power to discharge, is increased 50 billion times.

We can thus understand how it is that so long as masses of damp air are ascending in sufficient quantity to cause the great condensation and rainfall which usually accompanies thunderstorms, the tremendous discharges of lightning may be produced and accounted for without recourse to any special theory of its origin.

Lightning destroys about 250 persons per annum in America chiefly between April and September.

Lightning conductors act by equalising the flow of electricity between the air and earth and preventing a disruptive discharge.

They are now generally made of iron and must always be in contact with damp earth since they act not by drawing the atmospheric electricity down, but by allowing the earth electricity to flow upwards.

Even in perfectly clear weather there is a constant difference of electrical condition between the air and earth. In flying kites at Blue Hill near Boston with steel wire, a conductor has to

be attached to the earth, otherwise the observers even on a cloudless day experience severe shocks.

Lightning is of various kinds. Sometimes it branches out in all directions from cloud to cloud and is too far above the earth to strike through the intervening space. This frequently happens in the tropics where the author has often witnessed a beautiful electrical storm right overhead, the thunder of which was inaudible. At other times, especially in cyclonic thunderstorms, it occurs in lower clouds and strikes down to earth in what is termed forked lightning accompanied by loud thunder. Thunder is produced by the rapid heating and expansion of air by the discharge passing through it.

The noise is occasioned precisely in the same way as the sudden generation and expansion of gas which ensues upon the ignition of gunpowder in a confined space such as a gun.

The destruction of a tree or house is occasioned in like manner by the expansion of air or material which is unable to conduct the discharge. Upon a human being the effect is partly caused by heat and partly by shock to the nervous system.

A peculiar form of lightning is occasionally witnessed in which it descends from the clouds in a globular form.

These isolated globes of electricity play peculiar pranks, meandering slowly along in the most wayward and capricious manner, and apparently doing little damage until they burst. They are believed to be somewhat of the nature of Leyden jars in which a layer of air takes the place of the glass.

St Elmo's fire is an appearance sometimes seen on the masts of ships in stormy weather. Each mast head is surrounded by a faint luminous ball of electric light. It is really a brush discharge which takes place between the top of the mast and the highly charged atmosphere overhead.

The most violent storms of lightning and thunder in the world are probably to be found in the north westers of Bengal where the lightning is continuous for more than an hour at a time. This is due to the enormous condensation caused by the upward convection of the very damp air of that region. The most awe-inspiring electrical manifestations, however, frequently occur when a thunderstorm occurs in a region like Colorado where the air is usually dry. The author once experienced a storm at the Colorado Springs railway station in which every time a flash of lightning appeared, a miniature flash and loud report were simultaneously observed in the telegraph office. The wire of the conductor outside was fused, and upon one of the party venturing out with an umbrella up he returned declaring it was raining lead.

At the summit of Pike's Peak, 14,000 feet high in the same district, the observers in the now discontinued observatory used occasionally to experience most disagreeable shocks even in the simple act of shutting the door, while after walking across the room they could light the gas with their fingers. In Canada, in winter when the air is very dry and frosty, the same phenomena are frequently observed.

It was formerly supposed that thunder and hail were unknown in the Arctic regions, but Mr Harries of the Meteorological Office has recently shewn that they both occur right up to Spitzbergen and are fairly frequent in the Barents Sea. It seems possible that the warm ocean currents bring enough warmth and moisture to these cold regions to cause the vertical instability of the atmosphere which originates them.

The peculiar arched appearance of the clouds in norwesters, pamperos, and the arched squalls of tropical seas and higher latitudes is simply an effect of perspective caused by a long roll of cloud advancing athwart the spectator.

CHAPTER XIII.

SUSPENSION AND FLIGHT IN THE ATMOSPHERE.

THE conquest of the earth by man may be looked upon as tolerably complete. The conquest of the air has so far eluded all his efforts. Only for short periods and with great trouble and risk has he been able to mount into the air by the aid of balloons.

The balloon itself, old though it may appear to most of us, dates back only 100 years.

Lichtenberg of Göttingen, in 1781, was among the first to experiment, and made a small balloon of goat-skin, which ascended in the air when filled with hydrogen. Thomas Cavallo, an Italian

refugee, about the same time began by blowing soap bubbles filled with hydrogen, and watching them mount as the school-boy does to-day. Before he got much further, a step in advance was made in France by two brothers, Montgolfier, who curiously enough started by trying to make a cloud of steam ascend in a silk bag. On lighting a fire to increase the "cloud" they accidentally struck on the "hot air balloon," which has rendered their names famous.

The first human being to actually ascend in a balloon was Pilatre de Rozier on Nov. 21, 1783; but in this case ordinary coal gas was employed, and has ever since been generally adopted.

Soon after this, in 1785, Blanchard safely crossed the English channel in a balloon, and thenceforward ballooning came into fashion, though at first it was frequently attended with mishaps and loss of life. The parachute, which is now so familiar to the world through the recent beautiful descents effected by Baldwin, was first employed by Garnerin on Oct. 21, 1797. He then descended safely from a balloon, but experienced violent oscillations. These are now obviated by means of a central aperture through which the imprisoned air flows quietly upwards. The history of the balloon ascents of Lunardi, Tissandier, Fonvielle, Gay Lussac, Green, Nadar, Glaisher, and Coxwell is that of continual improvement, success, and safety. Their voyages, particularly those of the two last, have added considerably to our knowledge of the conditions of the upper air. Within quite recent years great strides have been made in the construction

of balloons, chiefly in relation to their use in operations of war, by the English military balloon department at Chatham.

The material employed is oxgut, which is capable of holding pure hydrogen without leakage. Since pure hydrogen is nearly 2½ times as light as coal gas, balloons filled with it have greater buoyancy and are better fitted to withstand the depressing influence of the wind when captive. A balloon of this material, which contains 10,000 cubic feet of gas, weighs only 170 lbs. The top valve is made of aluminium, and a telephone conductor is arranged for communication between the occupant of the car and those below. Men can readily be seen at a distance of two miles from the car, and general military reconnaisance, including photography can be conducted with considerable accuracy.

By the aid of balloons man has certainly succeeded in attaining suspension in mid air. They have not, however, aided him in travelling through the air towards some definite point. If he commits himself to them he must needs go *nolens volens* whither the wind may carry him. Far from having conquered the air as he has conquered the earth and the sea, he has hardly more power to guide himself in a balloon than a piece of straw hurled along by a whirlwind.

Some few years back Messrs Krebs and Renard in France were supposed to have solved the problem of the dirigible balloon by means of a cigar shaped balloon and a motor which drove a rotary fan screw at one end ; but though in

calm weather progress at some few miles an hour was obtained, it was found to be useless against the wind which ordinarily prevails at any considerable height above the earth's surface.

The late Prof. Helmholtz dealt a death-blow to the practical realisation of the dirigible balloon by shewing on theoretical principles that a balloon could not be driven against the air at a rate of more than twenty miles an hour without destroying its framework. To accomplish aerial locomotion therefore, we must look elsewhere.

From the earliest times the flight of birds has attracted the admiration and envy of mankind.

The ancient legend of Icarus who made a pair of wings and singed them off by flying too near to the radiant Phœbus, was evidently based on the desire man has always shewn, to be able to fly like a bird.

As long ago as 1470, that "preternatural genius," Leonardo da Vinci, in the intervals of painting the holy family, etc., amused himself by planning amongst other things flying machines. Moreover, he appears from his remarks, even then, to have realised that the main difficulty to be met with apart from elevating and motive power, was the question of balance.

The recent accidents by which those enthusiastic soarers, Herr Lilienthal of Steglitz and Percy Pilcher of England, lost their lives, occurred through their inability to accommodate their balance to a sudden gust of wind.

The early history of the attempts of man to fly is not calculated to inspire the human race with a belief in its intuitive sagacity. For the most part it is a history of miserable failures

and fatuous inability to realise the feebleness of human muscular power. The first serious attempt to grapple scientifically with the problem was inaugurated by Wenham in 1866 in a paper before the Aeronautical Society, in which the principle of suspension by soaring as well as flapping was alluded to.

Since that time great progress has been made in the development of what are termed flying machines by Prof. Langley of Pittsburgh, Hiram Maxim of England, Octave Chanute of Chicago, and Hargrave of Sydney.

In these machines no attempt is made to imitate the flapping by which birds mount into the air, but only of those principles by which many of them are enabled to soar or sail with outstretched wings when sufficient speed has been attained.

Although it is a fairly safe rule to follow Nature, exact imitation is by no means in every case necessary or advisable. Thus, just as in travel on the earth's surface, it has been found more convenient to employ the wheel than rapidly moving artificial legs, so in the atmosphere, it is better from an aerial engineering point of view to analyse the compound movement of a bird's wing into the two distinct elements, support and forward propulsion, and deal with them quite separately. In the case of the bird, the wing thrusts backwards, and also acts as an inclined plane, which, when it is forced horizontally through the air, converts the pressure into support. In the artificial flying machine, the back thrust is given by the fan

screw or aerial wheel at the rear of the plane, and the plane itself remains fixed at a certain angle.

The principle of the inclined plane is strictly analogous to that by which a kite is suspended when moored in a breeze. When the breeze fails, the boy converts his kite into a flying machine by running with it, and restoring support by the relative breeze thus created. If we cut the string of the kite and supply it with a motor and propelling fan, it will fly itself without the boy's aid, and become a veritable free flying machine. The kite, therefore, is the basis of the flying machine. A flying machine is a self-propelled kite

There are two actions of the wind on a kite or inclined plane. Partly it tends to make it drift to leeward, and partly to lift it upward. Certain birds, such as the Kestrel hawk, shewn in fig. (38), the eagle, vulture, and albatross, (especially the two latter), possess the power of obviating the tendency to drift, and of keeping themselves poised, or of sailing for long periods without flapping by the action of the wind on their wing planes. The precise way in which this is accomplished is not yet fully determined Maxim regards it as effected by an intuitive utilisation on the part of the birds of local upward currents which exist naturally, or else artificially up declivities.

The albatross of the southern seas which the author has frequently watched for hours and days together, undoubtedly makes use of the wind blowing up a wave to restore its lift,

after it has descended nearly to the surface of the water.

Prof. Langley, on the other hand, attributes the suspension in both hovering and sailing, more generally to a like intuitive adjustment on the part of the bird to certain rapid changes which are found to occur in the speed of the wind. When a strong gust comes, he slides down a little to meet it, and overcoming the

FIG. 38.—KESTREL HAWK HOVERING.

back drift entirely by his forward momentum, is able to utilise it simply for lifting him vertically to the same height he was at before. When the lull occurs, by lying flatter, he is able in this way to derive a larger proportion of lift from the lighter wind, and therefore maintains nearly the same elevation, and so on.

In the circular sailing so commonly seen when vultures sight a piece of carrion, the inclination

of the wing planes is similarly increased on the windward half and decreased on the leeward half of the circle.

The soaring and sailing of birds is only possible while the air is in motion. Directly there is a calm, even the Albatross is obliged to flap.

It is therefore only when a wind is blowing, that soaring can be exactly imitated by an intelligently controlled flying-machine. In any other case an artificial wind must be created by means of the rotating fan-screw in order to ensure support, and the plane must be kept constantly inclined upwards.

It will be long before man will be able to gain such a sense of flight as to be able to dispense with the motor of his flying machine and sail like the albatross without any apparent wing motion, but such a sense will doubtless gradually be developed as soon as he is fairly launched into the air, on what is termed the motor aeroplane, and future generations will witness the *ascent of man.*

The present position of human flight stands thus. Mr Maxim has built a large machine on the aeroplane principle, which on being propelled forward, has lifted itself and several people a few feet from the ground.

Professor Langley has made a small model machine actuated by a petroleum motor which has flown for a considerable distance while the motive power held out.

Mr Hargrave of Sydney is making a machine but no actual flight has yet been announced.

The basis of this machine is the so-called

cellular or double plane kite of which Mr Hargrave is the inventor, and which has recently been shown to be the most efficient and stable kite yet made.

Though a slavish imitation of bird architecture has never found favour with flying machinists, a study of birds, especially the large soaring and sailing birds, shows, what the Duke of Argyll in his 'Reign of Law' has so lucidly demonstrated, that birds fly "not because they are lighter, but because they are immensely heavier than the air. If they were lighter than the air they might float, but they could not fly. This is the difference between a bird and a balloon."

Any machine to travel through the air can only do so in consequence of its superior momentum. Consequently a flying machine must be heavy in proportion to the resistance it offers to the air.

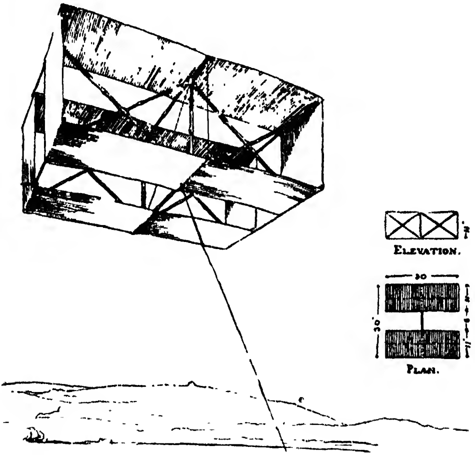
Another important point is deduced from the circumstance that a bird's wing presents a great length (from tip to tip) and narrow width to the wind.

For example, the wings of that king of flight the Albatross (*Diomedea exulans*) measure 15 feet from tip to tip and only 8 inches across.

There is a reason for this. When a plane surface is forced through the air, the upward pressure of the air is mostly concentrated near its front edge. If the surface extended far back from the edge, its weight would act at some distance from the front edge. Consequently the unbalanced pressure of the air would tend to turn the plane over backwards. If, however, its

width were small, the weight would act so close to where the resistance acts in the opposite direction that the forces would neutralise each other and stability ensue.

Mr Hargrave has adopted this principle in his cellular or box kite in fig. (39), whose construc-



tion is sufficiently obvious from the figure to render detailed description unnecessary.

The dimensions in the figure are in inches. The length of each cell (from right to left in figure) is 30 inches, and the width and height and opening between are about 11 inches; but these dimensions may vary, so long as the two

cells together form a nearly square area. An important feature of this peculiar tailless kite consists of the covered-in sides. These ensure stability even better than two planes, bent upwards in V shape, such as the wings of the kestrel when hovering, and they prevent the kite from upsetting, very much as the sides of a ship give it stability.

Mr Maxim once showed the advantage of such side planes by a simple experiment, in which a piece of paper, when held horizontally and let fall to the floor, is seen to execute a series of zigzags in the air, frequently ending in its complete overthrow; whereas, when the same piece of paper is folded up round the edges like a boat, it sails to the floor quite evenly, and in a straight line. The flying machine of the future seems destined to be built somewhat after this pattern.

The prime problem is to launch a stable aeroplane into the air, provided with an engine and screwfan powerful enough to drive it forward at the velocity required. Mr Maxim places his planes at a slope of 1 in 13, and his practical experiments have shown that the support gained by the pressure of the air on such planes is more than twenty times, and the motive power of the fanscrew thirteen times what had formerly been supposed. The engine which drives the fan is a very light one, actuated by petroleum. Hargrave estimates the entire weight of an engine to generate 3½ horse power at 30 lbs. It is placed in the hollow between the two cells in fig. (39).

Prof. Langley's recent experiment with his model over the Potomac showed that the elevating power derived from such an engine is sufficient. The main difficulty will be to ensure stability under *all* conditions, and to accommodate the apparatus to the varying currents, by the aid of movable front and side wings. To essay a journey except in a dead calm, without considerable practice, would at first probably end in mishaps. An era of preliminary misadventure, in fact, appears to be almost a necessary corollary to the establishment of every new form of locomotion. That success, however, will eventually be achieved is now the firm belief of all those who have studied the question.

The development of the flying machine will also be much assisted by improvements in the kite. The most efficient kite will be the most suitable aeroplane basis for the flying machine. The *kite* was first invented by the Chinese general, Han Sin, in 206 B.C., for use in war, and was frequently employed after that date in China, by the inhabitants of a besieged town, to communicate with the outside world. After this kites appear to have degenerated into mere toys.

At the middle of the present century, however, Pocock of Bristol employed them to draw carriages, and is said to have travelled from Bristol to London in a carriage drawn by kites. They were also occasionally employed to elevate thermometers to measure the temperature of the upper air, by Admiral Back on the *Terror*, and Mr Birt at Kew in 1847.

These observations had been quite forgotten when the author first suggested the employment of kites for systematic observations in 1883. It has since been discovered that Dr Wilson of Glasgow, as long ago as 1749, resuscitated kites from their long burial with a similar idea of employing them to measure temperature.

In the author's experiments, steel wire was first employed to fly them with. Two kites of diamond pattern made of tussore silk and bamboo frames were flown tandem, and four self-recording Biram anemometers weighing 1½ lbs. each were attached at various points up the wire. Heights from 200 to 1500 feet were reached by the instruments, and the increase of the average motion of the atmosphere was measured on several occasions for three years. Kites were also employed, first by the author in 1887, to photograph objects below by means of a camera attached to the kite wire, the shutter being released by explosion. Since that time kite photography has leapt into popularity, and has been successfully practised by M. Batut in France, Capt. Baden Powell in England, and Eddy in New Jersey.

The figure following represents a recent photograph of Middleton Hall, Tamworth, taken by Capt. Powell with a kite-suspended camera at a height of about 400 feet above the ground.

At the Blue Hill Meteorological Observatory, near Boston, Mass., which is carried on by Mr A. L. Rotch, tandems of kites are used to elevate a box of self-recording instruments, cameras, etc.

The adjoining fig. (41) shows the building, which is 630 feet above sea level, and a tandem of Hargrave kites supporting a camera with the adjustment involving the use of an extra cord for slipping the shutter, devised by Mr W. A.

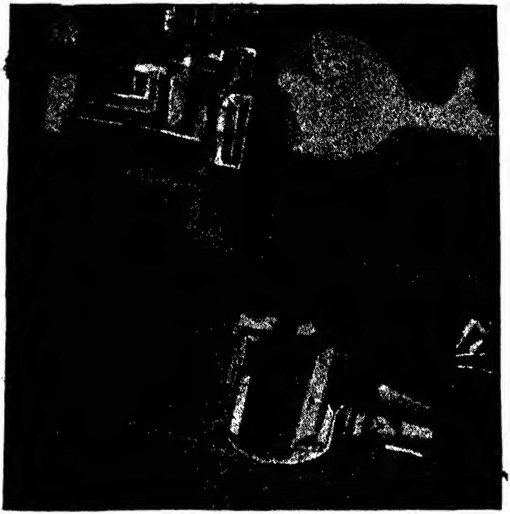


FIG 40.

Eddy. The height of the camera is determined by simultaneous observations of theodolites at the end of a base line.

By attaching several kites to the same main wire great altitudes have been reached at Blue Hill, and complete records of the pressure and

temperature recorded on a revolving drum of a Richard's thermograph and barograph.

The highest point attained in 1896 was 9385

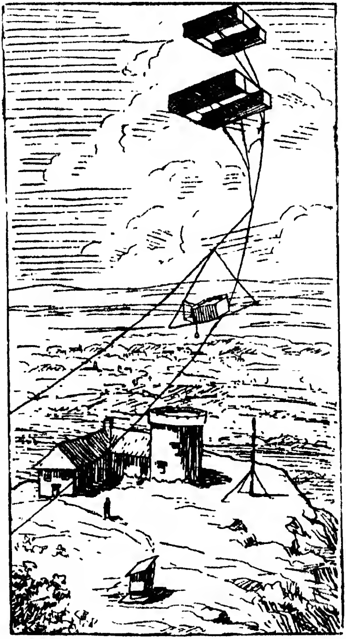


FIG. 41.

feet above sea level. In order to accomplish this, nine kites (of moderate size) and three miles of steel wire were required. At the

highest point the temperature fell to 20°, while at the observatory, 8755 feet below, it was 46°.

On other occasions in the same year when the author was present heights of 6079 and 7333 feet were attained.

Since the above heights were attained, Mr Rotch has, by adopting longer wire and steam hauling apparatus, succeeded several times in reaching heights of over 12,000 feet above the sea, and finally in July 1900 attaining 15,900 feet, or three miles and 60 feet above the sea. More than 200 records have been obtained at Blue Hill during the past five years from the ground up to this vast height, which exceeds that of Mt. Blanc.

As the author recently stated in the *Standard:*—

"The results open out a new chapter in meteorology.

"We learn what we only surmised before—that the successive cloud layers, which on the average tend to form about certain levels, coincide with air-streams which in point of velocity, temperature, and humidity, differ as much from the air above and below them as the Gulf Stream of the Atlantic does from the contiguous surface water. . . . Such streams, often moving twice as fast as the air above and below, must exert a marked influence upon the weather, and a knowledge of the position and character of at all events the one or two nearest the floor of our aerial ocean by means of kite sounding will obviously become a prime necessity in scientific work.

"Then, again, it is found that while the warm-

ing and cooling due to the alternation of day and night only affect our free atmosphere up to a very small height, say two or three thousand feet, the marked irregular changes of temperature—or, as they are popularly termed, waves of heat and cold—are found to occur simultaneously all through the air to a height of at least 10,000 feet. Another fact of great importance is that the greatest temperature at all heights, as a rule, nearly coincides with the lowest barometic pressure recorded at sea-level. . . . Over the cyclone the air is humid and the wind velocity is high and increases rapidly with the height. Over the anticyclone, on the contrary, the humidity is very low and the motion of the air very small at all times."

As Mr Rotch has recently remarked * :—"Whenever there is wind kites possess advantages over any other method of exploring the air up to a height of at least 12,000 feet.

"Although only on mountains can observations be maintained continuously at a uniform height, yet the conditions there are not those of the free air at an equal height.

"Observations in a drifting balloon are affected by the heated or stagnant air accompanying the balloon, and the progressive changes in the atmospheric conditions at one place cannot be studied. . . . Kites can rise much higher than captive balloons, which are borne down by the weight of the cable necessary to control them [and by the wind]. Finally, kites cost very

* *Technology Quarterly*, vol. xiii., No. 2, June, 1900.

much less than either mountain stations or balloons."

"It appears, therefore, that in future the equipment of a first-class meteorological observatory should include the kite . . . . so that automatic records may be obtained daily at the height of a mile or two in the free air at the same time that similar observations are made at the ground."

It was further suggested by the author in 1888,* that kites could be used for various purposes in war as well as science.

Since then Capt. Baden Powell, in May 1895, read a paper on "Kites, their uses in War." In both these publications it was pointed out that kites possessed several distinct advantages over balloons; next, that they could be applied to all the purposes for which balloons could be employed, such as signalling, photography, torpedo projection, carrying despatches between vessels, and lastly, they could be employed to raise a *man* for purposes of reconnaissance.

This question of "man raising" was long scouted as impossible, but both Capt. Powell and Mr Hargrave have practically proved its possibility by elevating *themselves* by kites, the former having reached a height of 100 feet.

To give an idea of the size of kite required for such a purpose, Capt. Powell was lifted by a single large kite spreading 500 square feet, weighing 60 lbs., and capable of folding into a

* Les Cerf Volants Militaires. Bibliotheque des Connaissances Militaires. Paris, 1888.

package 12 feet long. Mr Hargrave, at Stanwell Park, N. S. Wales, on Nov. 12th, 1894, was raised 16 feet by four kites flown tandem which spread together an area of 232 square feet, the wind blowing about 21 miles an hour. The total weight supported was 208 lbs. An ounce of fact is said to be worth a ton of theory. Here we see that in an ordinary 20 mile an hour wind a kite area amounting to 250 square feet is ample to support a man.

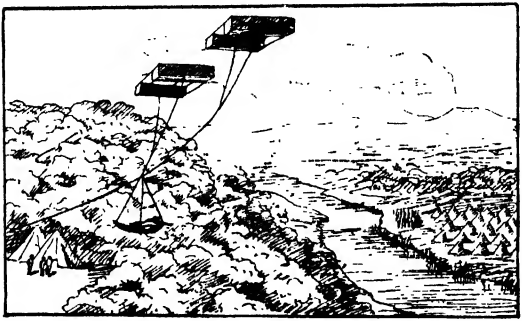


FIG. 42.

For a speed of only 10 miles an hour a larger surface would be required, but if the system of tandem kites recommended by Hargrave is followed, this could be readily attained by the addition of more kites. Under these circumstances, by two or more Hargrave kites a man could be raised, as in fig. 42, and effect a reconnaissance of an enemy's fortifications and dispositions, especially in mountainous country, with

considerable ease and far greater immunity than in a captive balloon.

The portability of such a series of kites even for man lifting may be guessed from the remark by Mr Hargrave, in his latest paper dated August 5, 1896, that "a nineteen square feet kite has been made, that weighs only 19 ounces, and folds to about the size of an umbrella. Ten of these could be tucked under one's arm, and with a coil of line and a decent breeze, an ascent could be made from the bridge of a torpedo boat or the top of an omnibus."

The torpedo boat certainly sounds more heroic, and probably less dangerous than the omnibus.

Numerous possibilities have been suggested by Capt. Baden-Powell, and there seems no reason why kites should not enter in as a regular part of the paraphernalia of naval and military operations.

Some few years back, the author, with a kite of the ordinary diamond pattern, 18 feet by 14 feet, was able to carry up 600 feet of steel rope cable, by which Col. Templer tethered his large war balloon in Egypt.

This weighed 50 lbs., and as an additional test, a man's kit weighing 10 lbs. was suspended to its tail. Two such kites could lift a man and pack away like fishing rods.

Quite recently (July 1896) a brochure by Prof. Marvin, dealing with the whole science of kites, has been published by the U. S. Weather Bureau. This represents the most complete discussion of kite-flying up to date, and one or two of the results are worthy of special record.

The best kites are double plane Hargraves, with certain improvements in details. Tandems of two kites only, with 9000 feet of wire out, have several times reached over 6000 feet in height.

Kites can be made to fly at angles of 60° or more, and utilise most of the wind pressure in lifting.

By adjusting the point of suspension or altering the kite, we can make it fly in the ideal position. This is found to occur when the direction of string or wire is inclined at an angle of 66° to the horizon, and cuts the kite plane at right angles, so that the latter is inclined at 24° to the horizon.

Also theory shews that, in order to gain the greatest effect when kites are flown tandem, the largest kite or a bunch of two ought to be placed at the top of the main wire.

In conclusion.—By balloons alone, man will never be able to complete the conquest of the air. For travel through the air, or as Prof. Langley terms it "aero dromics," steam propelled kites will be the future vehicle. For rest and observation in the air, kites will again be a serious rival of balloons. In fine, we may look upon kites as likely to take a very much more important place in the future than in the past story of our atmosphere.

Before closing this chapter, it is worthy of notice that the principle of the inclined plane is made use of in two other important applications of the motion of the atmosphere besides that of supporting kites—viz., in the sails of ships, and in windmills.

In the former, the wind meets the sail at a certain angle, and produces effects analogous to those on a kite, especially when the latter forges overhead, under the influence of a freshening breeze.

The water here acts like the controlling string, except that it allows the sail and boat to move through it, and, so to speak, form fresh attachments every instant. The slip to leeward is analogous to the lift in the kite, which is checked by the inextensibility of its string. The back drift is prevented by the pressure of the water, and the shape of the main-sail, which tends to make its forward part, and therefore the boat, turn continually towards the wind. The shape of the boat, the jib-sail, and the action of the rudder convert this turning-round force into continuous motion ahead.

As in the case of the kite, there is one position (different for each combination of sails and boat, and varying with the force of the wind) in which the greatest advantage or speed is attained for a given direction. To find this and maintain it is the object of the steersman.

In practice it appears to be very similar to the best inclination for a kite, so that for any wind between head and beam, the sail should not be inclined more than 24° to the keel. In the case of a *windmill*, "the angle of weather," as it is termed, or the angle which the sails make with the plane of rotation, answers to the angle between the keel and the boat-sail, and varies, according to circumstances, round an average of 24°.

Windmills are a means of converting the motion of the wind into mechanical energy, which may be employed either for pumping up water, grinding corn, or, as Lord Kelvin suggested in 1881, for generating electricity. Before the present coal-burning epoch, windmills

FIG. 43.—YACHTING IN SYDNEY HARBOUR.

used to be extensively employed for corn-grinding. To-day they are mostly employed in raising water for drainage, storage, or irrigation. Most railway stations, every farm-house, and almost every private country house in the Middle United States and Australia, have their windmill and tank. Labelled "cyclone" or "eclipse,"

according to their particular make, they form quite a feature of the landscape, and it is estimated that there are more than a million such mills in the United States alone.

The "useful efficiency" of windmills, especially in the modern geared form, is comparable with that of the best simple steam-engines.

A geared modern wheel, 20 feet in diameter, will develop 5 horse-power in an 18 mile an hour breeze, and can be applied to work agricultural machinery and dynamos for electric lighting. With a single wheel of this size, Mr M'Questen of Marblehead Neck, Mass., U.S.A., works an installation of 137 electric lights, for which he formerly used a steam-engine. As a result, he finds that he effects a saving of more than 50 per cent.

According to Lord Kelvin, wind still supplies a large part of the energy used by man. Out of 40,000 of the British shipping, 30,000 are sailing ships, and as coal gets scarcer, "wind will do man's work on land, at least in proportion comparable to its present doing of work at sea, and windmills or wind motors will again be in the ascendant."

CHAPTER XIV

LIFE IN THE ATMOSPHERE

THE limits of space warn us abruptly that we must bring our story to a close And yet, facing us in the book of nature, there is a large unwritten story of how the atmosphere affects the lives of men and plants, embracing questions connected with weather, climate, disease, hygiene, agriculture, sanitation.

The chief elements of climate have already been dwelt upon in the chapter on temperature and rainfall.

Hygiene and sanitation open out points in which other factors, such as soil enter as well as air.

The relations of the atmosphere to agriculture, though a subject of immense interest to the agriculturist, is not a fascinating one to the general public. Prof. Hilgard, of the University of California, has exhaustively discussed this theme in a bulletin published by the U.S. Weather Bureau, 1892, and Sir J. B. Lawes and Professor Gilbert have carried out experiments in England, at Rothampsted, all of which show that in order to derive our maximum subsistence from the soil, we must have a thorough knowledge of the actions which take place between it and our atmosphere.

The relation of climate to life, health, and disease is a very wide one, and though it has attracted man's attention for years, it has only

recently been studied with anything like scientific accuracy. An excellent summary of the principal modern results will be found in Moore's Meteorology.

As an example of how disease is dependent on season, the following table will suffice :—

Disease.	Development measured by Mortality. Maximum.	Minimum.
Enteric fever,	Oct., Nov.	May, June.
Smallpox, .	Jan. to May.	Sept., Oct.
Measles, .	June, Dec.	Mar., Oct.
Scarlet fever,	Oct., Nov.	Mar. to May.

The opposition between enteric and smallpox, in regard to season, shows clearly that seasonal conditions have a great deal to answer for in the development of disease.

There is little doubt that besides the regular effects of seasonal changes, the quality of the air of a place is a potent factor in relation to health.

We talk of going away for *a change of air*, and we know that beneficial effects usually follow if we choose our fresh locality aright.

The air of cities, as we have seen, contains vastly more dust particles than that of the country, and it is full of other impurities, thrown off by the multitudes of human beings crowded together in a small space.

The pallor of children in cities compared to the ruddy health of those who dwell in the comparatively unpolluted country air is well known. Similarly the air on mountains and high plateaux is less dusty and vastly purer than that near sea-level.

In certain parts where vegetation decays in presence of water, noxious exhalations arise called significantly mal-aria (bad air), and cause fevers not only in the Mangrove Swamps of the tropics, but formerly even in the undrained fen-districts of England.

This bad air usually remains quite close to the ground, and its effects can often be obviated in the tropics by sleeping on an upper floor.

The atmosphere undoubtedly acts in many cases as a disease propagator by conveying germs from one place to another.

For example the mysterious influenza, which has of late years so afflicted the whole world, is evidently propagated through the air. As a rule, however, water is a far more effective disseminator of disease than air, and where a good water supply has been established, in many parts of India, where formerly cholera was rife, it now occurs very rarely and in a milder form.

In general, the atmosphere acts as a health and life giver.

The more fresh air we breathe, the more we dilute the poisons which would otherwise harm our systems.

We are no doubt temporarily and permanently affected by the particular *climate* we live in, as well as by the air we breathe.

Climate is an average of the general weather conditions, and is chiefly determined by the temperature, rainfall, humidity, sunshine, and winds which prevail in a district.

All the regular and irregular variations men-

tioned in chapters (IV.) and (VIII.) are involved, particularly annual and daily temperature ranges.

At some seasons a change to a drier and warmer climate such as that of Egypt or Colorado is desirable.

Sometimes a mild one like that of Madeira or New Zealand is recommended, while a return to England or Europe is often indispensable to the Anglo-Indian who has endured years of Indian heat.

Permanent residence in different climates tends to develop certain national characteristics.

Thus the dry, rapidly changeable, continental climate of North America, accounts for the activity and impulsive go-aheadness by which the Americans are characterised. At the same time it accounts for their liability to neuralgia.

The debilitating, nerveless lassitude of the natives of tropical coasts is directly due to the moisture and heat.

The dry heat of central India and Arabia developes the martial energy of the Sikh and the Bedouin, while the mild but cool and temperate climate of England and Western Europe is distinctly accountable for the well-balanced mental and physical development of the races which have hitherto ruled the world.

Climates may be hot or cold, moderate or extreme (*i.e.*, of small or large range), dry or damp, calm or boisterous.

It was formerly deemed sufficient to pay attention to the temperature alone, but it has now been found that the other factors are equally important.

Even in regard to temperature, the average for the year is no safe criterion. The average

is an artificial centre, round which the values oscillate, and may be very seldom experienced. The ranges are far more important.

Thus Calcutta, in Bengal, has the same mean temperature of 77·7° F., as Agra, in the North-West Provinces, but their climates are very different when the ranges of temperature are considered. The difference of average temperature between the hottest and coldest months at Agra is 34°, at Calcutta only 20°. The average daily range at Agra is about 30°, at Calcutta only 16°.

When we touch rainfall and humidity we find Agra has only 29 inches to Calcutta 65 inches; while if 5 represents the humidity at Agra, 8 represents the amount at Calcutta. Agra also has half the cloud, and therefore about double the bright sunshine of Calcutta. Such instances could be multiplied indefinitely.

Here, therefore, we have two places situated in the same river valley, only 4° of latitude apart, and yet with totally different climates.

To attempt to group climates together over large areas is therefore impossible, except very roughly.

The old divisions of one torrid, two temperate and two arctic zones served as a rough outline. They are totally inadequate to explain the variations found at places not far apart within the same zone.

The only way to gain an idea of the climate of a place, apart from a study of actual figures, is to have a clear idea of the effects of all the different factors, such as—

(1) Latitude.

(2). Hemisphere, north or south.

This makes a great difference. The temperature ranges are far smaller in the Southern hemisphere.

(3) Situation with respect to large continents, particularly east or west. If on the east, as the U.S. or China, the temperature ranges, daily and seasonal, are much greater than on the west sides.

(4) Position, oceanic, coastal, or continental. This affects both temperature range, and humidity very largely.

(5) Elevation above the sea, and whether isolated or on a tableland. If the former, the climate is moderate; if the latter, extreme. In both cases the general temperature diminishes about 1° F. for every 300 feet of elevation above sea-level.

(6) Situation with respect to neighbouring mountain ranges, especially leeward or windward, with reference to prevailing winds. If on the windward side, such as Mull, Coimbra in Portugal, Vancouver, Bombay, Colombo, Valdivia in Chili, Brisbane, and Chirrapunji in Assam, the rainfall is often over 75 inches, while correspondingly on the lee sides of the adjacent ranges we find, Aberdeen, Salamanca (less than ten inches), Cariboo (east of the Coast range), Poona, Bandarawela, Bahia Blanca, Roma, and Shillong, with amounts varying from 20 to 30 inches only.

(7) Situation with respect to prevalent winds, trades, anti-trades, monsoons. This determines the season of rain, such as the monsoon rains in the Indian summer, whereas the summer in

Australia, exposed to the trades, is the dry season. The temperature conditions are thus considerably modified.

(8) The neighbouring oceanic currents. The effects of these have already been alluded to on p. 64.

(9) The nature and covering of the adjacent land.

(10) Situation with respect to the tropical or circumpolar rain and wind-belts.

As types of various general climates at sea-level, the following may serve as illustrations.

CLIMATES.

Type.	Examples.	Description.
(1) Equatorial, lat. 0° to lat. 10°,	Batavia, Colombo, Singapore, Cumana,	Hot, moist, equable, salubrious.
(2) Tropical, lat. 10° to 23°—		
(*a*) Coastal,	Calcutta, Hong Kong,	Similar to (1) but less equable and salubrious.
(*b*) Inland,	Lanore, Delhi, Mandalay. Timbuktu,	Hot, dry, and extreme, trying, except in winter.
(3) Sub-Tropical, lat. 23° to lat. 35°, or 40°,	Riviera, S. California, Cape Colony, Southern Australia,	Temperate and dry, owing to position between tropical and polar rain-belts, very salubrious

Type	Examples.	Description.
(4) Temperate—		
(*a*) North, lat. 35° to lat. 60°	England, Europe, UnitedStates Central Siberia, and China.	Cool, moist, and equable near sea, dry and extreme inland.
(*b*) South, lat. 35° to lat. 50°,	New Zealand, Tasmania,	Cool, moist, and equable, most salubrious in the world.
(5) Polar, lat. 60° to poles,	N. Siberia, Greenland,	Cold and fairly dry, extreme inland.

Judged by averages alone, a climate with an annual average temperature between

75°	and	85°	is hot.
65°	„	75°	is warm.
55°	„	65°	is mild.
50°	„	55°	is temperate
40°	„	50°	is cold.
Below		40°	is arctic.

These adjectives are, however, only applicable when the range is small between summer and winter.

Man can never hope to control or sensibly alter the climate of the countries in which he is placed. Nature works on too vast a scale. He can, however, by studying the different kinds of climate and their properties, discover

which are suitable for certain diseases and ages, and by utilising this knowledge, to some extent shelter himself against influences which are recognised to be hostile, and which lead not merely to loss of individual life and health, but to degeneration of the human race.

INDEX.

TURNBULL AND SPEARS, PRINTERS, EDINBURGH.